Environmental Studies No. 57

Yukon Fish and Effects of Causeways

Canada

Environmental Studies No. 57

Yukon Fish and Effects of Causeways

Northern Affairs Program

W.B. Griffiths, R.G. Fechhelm,
B.J. Gallaway and D.B. Fissel

LGL Ltd.
Environmental Research Associates

Arctic Science Ltd.

Published under the authority of the
Hon. Bill McKnight, P.C., M.P.,
Minister of Indian Affairs and
Northern Development,
Ottawa, 1988.

QS-8426-000-EF-A1
Catalogue No. R71-19/57-1988E
ISBN 0-662-16578-0

©Minister of Supply and Services Canada

This Report was prepared under contract for the Northern Oil and Gas Action Program (NOGAP), Natural Resources and Economic Development Branch, Department of Indian Affairs and Northern Development.

The views, conclusions and recommendations expressed herein are those of the authors and not necessarily those of the Department.

Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

90-04620/

PREFACE

The extensive exploratory drilling activities in the nearshore waters of Canadian Beaufort Sea and in the Mackenzie Delta region have resulted in the discovery of potentially commercial quantities of hydrocarbon resources. As plans for extracting these resources move ahead, a variety of developments have been proposed of shore-based facilities along the Yukon coast. These developments typically incorporate a solid-fill causeway in conjunction with either dredged channels or solid-fill breakwaters. The possibility of the construction of these structures in the nearshore waters of the Yukon coast has led to a concern by government agencies about the effects these developments will have on the population levels of anadromous fish that use this coast as a migration route or as summer feeding habitat.

At present there are insufficient biological and physical data from the Yukon coast to allow for a determination of the potential impacts of these structures on fish populations. However, these same questions have been the subject of massive studies related to the two causeways--West Dock (Waterflood) and Endicott--in the Prudhoe Bay/Sagavanirktok Delta region of Alaska. These multi-million dollar studies have been ongoing since 1981, and have resulted in the accumulation of extensive amounts of meteorological, oceanographic and fisheries data, in order to determine the factors controlling the effects of nearshore structures on fish populations. The data that have been generated from the Alaskan studies have been organized into a computerized database in order to facilitate the handling and interpretation of such a large amount of information (in excess of 267,000 lines of data through 1985).

The present study has been divided into three parts. The first part is a synthesis of the Alaskan information, produced using the database, that addresses the extent of the effects of the two Prudhoe Bay/Sagavanirktok Delta causeways on anadromous fish populations. In the second part, this synthesis and the available data from the Yukon coast are combined to assess the likelihood that coastal structures along the

Yukon would affect the anadromous fish populations using the area. The third portion of the study provides an evaluation of the data that are available from the Yukon coast and their usefulness in addressing the relevant questions of development-related impacts. In addition, the important data gaps are identified and recommended priorities for future studies are provided. In total the report illustrates how the position of the U.S. agencies has evolved, primarily from an early concern of causeway-induced blockage of anadromous fish movements and migrations to the present day concern for population levels of these fish.

EXTENDED ABSTRACT

The general purpose of this study was to produce a synthesis of the relevant information on the effects of causeways in the Prudhoe Bay/Sagavanirktok Delta region of Alaska, on the distribution, movement and population levels of anadromous fish. This synthesis and the available data from the Yukon coast were then combined to assess the potential impacts of coastal structures on anadromous fish populations along the Yukon coast. Important data gaps are identified and recommendations for future studies are provided. In addition, a review of the present and historical positions and views of the U.S. regulatory agencies on the impacts of causeways on anadromous fish is provided. The specific objectives of the study were to:

1. Prepare a synthesis of the relevant Alaskan data on the effects of nearshore structures on anadromous fish populations and habitats.

2. Evaluate potential effects of structures along the Yukon coast using the above synthesis and the available data from the Yukon coast.

3. Provide an analysis of the adequacy of the available data from the Yukon coast to address the relevant questions.

Part 1: Effects of Causeways in the Alaskan Beaufort Sea on Anadromous Fish Populations

Wind-driven water masses in the nearshore region of Prudhoe Bay, Alaska, are altered by the presence of solid-fill causeways. After periods of strong easterly winds, intense upwellings of cold, saline water form on the west side of the West Dock causeway, and surface water is deflected from the east side around the causeway's tip as a warm, brackish, buoyant plume. During westerly winds, warm brackish water from the barrier island-lagoon system to the west of West Dock flushes around the causeway into Prudhoe Bay. A similar pattern of events occurs at the Endicott causeway, with the exception that the marine upwelling on the west side of the structure is much less intense during easterly winds than is the case for West dock.

In the Prudhoe Bay/Sagavanirktok Delta region, two marine species (Arctic cod and fourhorn sculpin) and four anadromous species (Arctic and least cisco, Arctic charr and broad whitefish) have accounted for between 95 and 98% of all fish taken by fyke net from 1981 to 1986. The four anadromous species were chosen as the focal points of the synthesis.

West Dock and the Endicott causeways appear to have minimal effect on the distribution patterns and movements of large (>250 mm FL) individuals of all four anadromous species. The effects are also minimal for small (<250 mm FL) Arctic charr, because they disperse widely along the coast to feed, and for small broad whitefish, because they either disperse to such a limited extent that they rarely encounter the causeway (West Dock), or they use the breaches to move across the Sagavanirktok Delta (Endicott causeway).

Small Arctic and least cisco from the Colville River can be delayed or blocked by West Dock from entering the Prudhoe Bay region, during periods of strong and persistent easterly winds early in the season. The Endicott causeway appears to have a minimal effect on small

Colville and Sagavanirktok river Arctic cisco and Colville River least cisco.

The major impact of causeways in relation to fish habitat is that they can potentially exclude fish from their preferred feeding areas. West Dock and the Endicott causeway appear to have minimal effect on the feeding habitat of either large Arctic charr, broad whitefish, Arctic cisco and least cisco or small Arctic charr and broad whitefish. However, West Dock has the potential to block small Arctic and least cisco from reaching about 30% of their preferred summer feeding habitat.

The ultimate question is whether the causeways affect the population levels of the anadromous species. The West Dock and Endicott causeways do not appear to pose a threat to Arctic charr and broad whitefish populations in the region. Although West Dock can block the passage of small least cisco, only about 5% of this size-class of Colville River least cisco move far enough east to be affected, so that population level impacts are not likely. The case for arctic cisco is not as clear. If the number of age 0^+ Arctic cisco that migrate from the Mackenzie over to Alaskan waters represents a substantial portion of the Mackenzie population, or if they are composed of a single Mackenzie stock, rather than a mix of stocks, then there is a potential for population level impacts for Arctic cisco.

Part 2: Potential Effects of Causeways at King Point and Stokes Point, Along the Yukon Coast

Two potential development sites were selected along the Yukon coast, King Point and Stokes Point. The King Point development consists of a solid-fill causeway plus a breakwater, and the Stokes Point plan calls for a solid-fill causeway and a dredged channel.

The oceanography at both King Point and Stokes Point has large time-dependent variations, particularly under east winds, because of the presence of the Mackenzie River plume.

The potential effects of the proposed causeways on the local oceanography are similar at both sites. During easterly winds, the westward transport of warm brackish water would be disrupted, and pools of cold, saline water would form on the west side of the structures. Alterations in the oceanography would be much less during periods of westerly winds.

Previous studies have shown that Arctic cisco, least cisco and Arctic charr accounted for about 87% of the total catch in the region; however, only Arctic and least cisco occurred in abundance. A fyke net study in Phillips Bay showed that small (<250 mm FL) Arctic and least cisco were the most abundant groups, in terms of numbers, using the region during the open-water season. Consequently, Arctic and least cisco have been selected as the species of concern.

It is unlikely that the proposed structures at King Point and Stokes Point would affect large Arctic and least cisco, given the relatively small size of these structures and the swimming capabilities of these large individuals. However, the case for small Arctic and least cisco is not as clear, since there are insufficient data on the distributions and movements pattern of these groups to allow for a determination of the impacts of the proposed structures.

Population level effects for least cisco and Arctic cisco would depend on what percentage of the Mackenzie stocks of each of these species utilizes the Yukon coast, or whether the least cisco and Arctic cisco are from single or mixed stocks. The answers to these questions are not known at present.

Part 3: Adequacy of the Available Information and Important Data Gaps in Relation to Yukon Causeways

The available physical data are insufficient to allow for a determination as to how the proposed structures at either King Point or Stokes Point would alter the water masses. To address this deficiency would require the collection of oceanographic and meterorological data on a daily basis at each site over the open-water season. The data should be collected on a grid pattern from shore out to 3 km and approximately 5 km on either side of the proposed development. In addition very high resolution thematic mapper from the Landsat satellite could be used to resolve the coastal zone oceanographic features.

The major problem confronting the Alaskan monitoring programs is the lack of site-specific pre-construction fisheries data with which to compare the results of the on going studies. There are no seasonal fisheries data available for the specific development sites. Although there are seasonal gill net and seine data for 1985 and daily fyke net data for 1986 from Phillips Bay, located between King Point and Stokes Point, this site is sufficiently different (i.e., a shallow bay with river discharge) to make extrapolations to the development sites difficult.

To address the data gaps would require the collection of baseline fisheries data from a number of years to ensure that information is available for the various wind regimes to take into account the natural variability within the system.

The types of studies required would include mark/recapture programs which can provide detailed information on distribution patterns and timing of movements. The collection of age/length and length/weight data, especially for small Arctic and least cisco, over a number of years, both at development sites and remote from them can be used to determine alterations in habitat caused by the presences of causeways.

The two most important unanswered questions are (1) what percentage of the Mackenzie Arctic cisco migrate over to Alaska? and (2) are these fish from a single stock or are they composed of a mix of stocks? Future studies should be designed to provide the types of data needed to address these two issues. These would include mark/recapture studies, catch comparison studies conducted simultaneously on both sides of the Mackenzie Delta, and stock separation studies.

TABLE OF CONTENTS

	PAGE
PREFACE	i
EXTENDED ABSTRACT	ii
TABLE OF CONTENTS	viii
LIST OF TABLES	xii
LIST OF FIGURES	xiii
SOMMAIRE	xv
PART 1: EFFECTS OF CAUSEWAYS ON ANADROMOUS FISH POPULATIONS IN THE ALASKAN BEAUFORT SEA	
INTRODUCTION	1
STUDY AREA	1
HISTORY OF CAUSEWAY CONSTRUCTION	2
PHYSICAL PROCESSES	6
Seasonal Ice Cycle	6
Seasonal Hydrographic Cycle	7
Local Physical Processes and the Role of Causeways	8
Northeast Winds	8
Northwest Winds	11
BIOLOGICAL SETTING	13
General Description of Fish Community	13
Anadromous Fish Feeding Cycle	15
Sources of Key Species	16
Arctic Cisco	16
Least Cisco	22
Arctic Charr	22
Broad Whitefish	23
Fish Habitat	24
Habitat Types	24
River Deltas and Estuaries	24
River Plumes	24
Lagoons	25
Bays	25
Ice Edges	26
Importance of Nearshore Habitats	26

Page

Habitat Conditions 27
Fish Prey 27
Distribution of Fish Prey 29
Water Temperature 30
Salinity 33
Currents 33

EFFECTS OF CAUSEWAYS ON FISH AND THEIR HABITATS 35

Least Cisco 35
General Movement Patterns 35
Effects of West Dock Causeway 37
Effects of Endicott Causeway 40
Cumulative Effects of West Dock and Endicott Causeway 41
Arctic Cisco 41
Colville River Stock/Effects of West Dock Causeway 41
Colville River Stock/Effects of Endicott Causeway 43
Sagavanirktok River Stock/Effects of West Dock Causeway 44
Sagavanirktok River Stock/Effects of Endicott 47
Cumulative Effects of West Dock and Endicott Causeways 47
Arctic Charr 48
General Movement Patterns 48
Effects of West Dock Causeway 49
Effects of Endicott Causeway 50
Cumulative Effects of West Dock and Endicott Causeways 50
Broad Whitefish 50
General Movement Patterns 50
Effects of West Dock Causeway 52
Effects of Endicott Causeway 52
Cumulative Effects of West Dock and Endicott Causeways 53
Effects on Fish Populations 53
Arctic Charr 53
Broad Whitefish 54
Least Cisco 55
Arctic Cisco 55
Breach Effectiveness 61
Potential Benefits of Causeways 63

SUMMARY 64

Page

PART II: POTENTIAL EFFECTS OF CAUSEWAYS AT KING POINT AND STOKES POINT ON THE YUKON COAST

INTRODUCTION 68

STUDY AREA AND PROPOSED DEVELOPMENTS 68

Stokes Point 70
King Point 70

PHYSICAL PROCESSES 72

Wind 72
River Discharge 74
Sea-Ice Conditions 76
Oceanographic Conditions 78
Stokes Point 80
King Point 82
Effects of Causeways on Oceanography 85

BIOLOGICAL SETTING 87

General Description of Fish Community 88
Fish Species of Concern 92
Broad Whitefish 92
Arctic Charr 92
Least Cisco 93
Arctic Cisco 93
Movement and Distribution Patterns of Key Fish Species 93
Least Cisco 94
Arctic Cisco 96
Effects of Structures on Yukon Fish 97
Stokes Point Causeway 97
Easterly Winds 98
Westerly Winds 99
King Point Causeway 99
Easterly Winds 99
Westerly Winds 100
Summary 101
Effects of Structures on Population Levels of Key Species 102
Least Cisco 102
Arctic Cisco 103
Causeway Breaches 104

SUMMARY 104

Page

PART III: ADEQUACY OF AVAILABLE INFORMATION AND IMPORTANT DATA GAPS IN RELATION TO YUKON CAUSEWAYS

INTRODUCTION 107

Oceanographic Data 107
Fish Data 108
Baseline Data 109
Limitations of the Available Data 109

Important Data Gaps 111
Population Studies 111
Mark/Recapture 112
Age/Length Data 112
Condition Factors 113
Feeding/Prey Studies 113

SUMMARY 114

LITERATURE CITED 116

LIST OF TABLES

Table		Page
1	Species composition of fish caught in fyke nets in the Prudhoe Bay, Sagavanirktok Delta area from 1981 through 1986	14
2	Principal stocks of important anadromous fishes between the Mackenzie River and Point Barrow, Alaska	18
3	Multi-year recapture rates for large anadromous fish tagged in the Prudhoe Bay area	20
4	Recapture rates of Arctic and least cisco tagged in Prudhoe Bay area and recaptured at Helmericks fishery	21
5	Summary of available nearshore oceanographic data off King and Stokes Points in summer	79
6	Species composition of fish caught in gill nets along the Yukon Beaufort Sea coast, 1974 through 1985	89
7	Species and group composition of fish caught in gill nets and seines during 1985 and in fyke nets during 1986 in Phillips Bay, Yukon Territory	90

LIST OF FIGURES

Figure		Page
1	Central Alaskan Beaufort Sea coast	3
2	Completed and the proposed solid-fill and breached causeways in the Prudhoe Bay/Sagavanirktok Delta area	4
3	Representation of water mass movements under northeast and northwest wind conditions	9
4	Generalized circulation patterns under strong northeasterly winds	10
5	Generalized circulation patterns under strong northwesterly winds	12
6	Beaufort Sea coast from Point Barrow, Alaska, to the Mackenzie Delta, Northwest Territories	17
7	Carbon sources and trophic relationships for Beaufort Sea coastal areas	28
8	Generalized depiction of the extent of warm water habitat in the central Beaufort Sea	32
9	Conceptualized map of least cisco migration patterns under northwesterly winds and under northeasterly winds	3o
10	Catch-per-unit-effort of small Arctic cisco east and west of West Dock for the 1981 open-water season, for the period 30 July to 9 August 1981, and water temperature for the period 30 July to 9 August 1981	45
11	Comparison of growth rates of Arctic cisco collected in Prudhoe Bay in 1983 with those collected west of the West Dock causeway during 1983 and 1984	57
12	Catch-per-unit-effort of Arctic cisco at the Colville River commercial fishery by year and the percentage of easterly wind during the summer of their recruitment	60
13	Length frequency of Arctic cisco in Prudhoe Bay at the start of the 1984 season	62

Figure		Page
14	Yukon coast from Shingle Point, Herschel Island	69
15	Map of Stokes Point and King Point showing proposed developments at each site	71
16	The directional distribution of winds at stations along the Beaufort Sea coast	73
17	The extent of the Mackenzie River plume, as shown in the 1980 to 1983 satellite imagery data, under dominant west-northwesterly and southeast-northeasterly wind conditions	75
18	Mid-July locations of the ice edge from 1971 to 1985 inclusive	77
19	Maps of surface temperature on 3, 5, 6 and 8 September 1986 off the Yukon coast	83
20	Measurements of temperature, current speed and direction at 5 m depth off King Point, 30 August to 6 September 1985	84

SOMMAIRE

Les nombreux forages d'exploration réalisés dans les eaux côtières de la mer de Beaufort (Canada) et dans la région du delta du Mackenzie ont permis de découvrir des réserves potentiellement commerciales d'hydrocarbures. Dans le cadre des plans d'extraction de ces ressources, la construction de diverses installations a été proposée le long de la côte du Yukon. Ces installations comprennent habituellement une chaussée sur digue remblayée pleine et combinée soit à des chenaux dragués, soit à des brise-lames remblayés pleins. La construction possible de ces ouvrages dans les eaux littorales du Yukon a incité les organismes gouvernementaux à se préoccuper des effets qu'ils auront sur les populations de poissons anadromes utilisant les eaux littorales comme voie de migration ou comme habitat d'alimentation d'été.

Les données biologiques et physiques recueillies à ce jour sur les eaux littorales du Yukon ne sont pas suffisantes pour déterminer les répercussions possibles de ces ouvrages sur les populations de poissons. Cependant, ces mêmes questions ont fait l'objet d'études approfondies en Alaska dans la région de la baie de Prudhoe et du delta du Sagavanirktok, où sont situées deux digues (West Dock [Waterflood] et Endicott). Ces études de plusieurs millions de dollars se poursuivent depuis 1981 et ont permis d'accumuler d'énormes quantités de données sur la météorologie, l'océanographie et les pêches et de déterminer comment les ouvrages côtiers influent sur les populations de poissons. Les données recueillies dans le cadre des études réalisées en Alaska ont été emmagasinées dans une base de données informatisée pour faciliter la manipulation et l'interprétation d'une aussi grande quantité de renseignements (plus de 267 000 lignes de données à la fin de 1985).

La présente étude a été divisée en trois parties. La première partie est une synthèse des renseignements recueillis en Alaska, établie en utilisant la base de données. On y traite de l'importance des effets sur les populations de poissons anadromes des deux chaussées sur digue de la baie de Prudhoe et du delta du Sagavanirktok. Dans la deuxième partie, cette synthèse et les données disponibles sur le littoral du Yukon sont combinées pour évaluer si les ouvrages qui seront construits le long du littoral du Yukon affecteront les populations de poissons anadromes qui évoluent dans cette zone. La troisième partie de l'étude présente une évaluation des données disponibles sur le littoral du Yukon et de leur utilité pour l'étude des questions qui se posent concernant les répercussions de l'aménagement de la zone littorale. De plus, on a déterminé les secteurs pour lesquels les données sont largement insuffisantes et fait des recommandations sur les études futures à réaliser en priorité. En somme, le rapport illustre l'évolution de la perspective des organismes américains, lesquels se sont surtout préoccupés au début de l'interruption des déplacements et des migrations des poissons anadromes par les chaussées sur digue pour s'inquiéter maintenant des effectifs des populations de ces poissons.

RÉSUME AUGMENTÉ

La présente étude a pour objectif général de produire une synthèse des données pertinentes sur les effets des chaussées sur digue dans la région de la baie de Prudhoe et du delta du Sagavanirktok (Alaska) sur la répartition, le déplacement et les populations de poissons anadromes. Cette synthèse et les données disponibles sur le littoral du Yukon ont été combinées afin d'évaluer les répercussions possibles des ouvrages côtiers sur les populations de poissons anadromes le long du littoral du Yukon. On y fait état de l'importante de données dans certains secteurs et on y presente des recommandations pour la réalisation d'études futures. De plus, on y examine les opinions et les perspectives, actuelles et passées, des organismes de réglementation américains sur les répercussions des chaussées sur digue sur les poissons anadromes. Les objectifs visés par cette étude sont les suivants :

1. Préparer une synthèse des données pertinentes sur les effets des ouvrages côtiers sur les populations et les habitats des poissons anadromes en Alaska.

2. Évaluer les effets possibles des ouvrages construits le long du littoral du Yukon en utilisant la synthèse mentionnée ci-haut et les données disponibles pour la côte du Yukon.

3. Produire une analyse de la pertinence des données disponibles concernant le littoral du Yukon pour l'étude des questions qui se posent.

Partie 1 : Effets des chaussées sur digue dans la mer de Beaufort en Alaska sur les populations de poissons anadromes

Le cours des masses d'eau entrainées par le vent dans la région littorale de la baie de Prudhoe (Alaska) est modifié par la présence de chaussées sur digue remblayées pleines. Après des périodes de vents d'est violents, il se produit des remontées importantes d'eau froide saline du côté ouest de la digue West Dock, tandis que du côté est, l'eau superficielle est défléchie autour du musoir de la digue sous forme d'un panache léger d'eau chaude et saumâtre. Lorsque le vent souffle de l'ouest, une eau saumâtre chaude provenant du complexe d'iles-barrières et de lagunes situées à l'ouest de la digue West Dock se déverse dans la baie de Prudhoe en contournant la digue. Des phénomènes semblables se produisent à la digue Endicott; cependant, la remontée d'eau marine à l'ouest de cet ouvrage y est beaucoup moins intense en période de vent d'est.

Dans la région de la baie de Prudhoe et du delta du Sagavanirktok, on a dénombré deux espèces marines (la morue polaire et le chaboisseau à quatre cornes) et quatre espèces anadromes (le cisco arctique, le cisco sardinelle, l'omble chevalier et le corégone tschir) qui représentent de 95 à 98 p. 100 des poissons pêchés par verveux entre 1981 et 1986. Ces quatre espèces de poissons anadromes ont été choisies comme points centraux de la synthèse.

Les digues West Dock et Endicott semblent avoir peu d'effets sur la répartition et le déplacement des gros individus (longueur à la fourche > 250 mm) des quatre espèces anadromes. Les effets sont aussi peu importants sur le petit (LF < 250 mm) omble chevalier étant donné qu'il se disperse largement le long du littoral pour s'alimenter, et sur le petit corégone tschir dont l'aire de dispersion est si restreinte qu'il atteint rarement la digue (West Dock) ou qu'il emprunte les brèches de l'ouvrage pour traverser le delta du Sagavanirktok (digue Endicott).

L'entrée dans la baie de Prudhoe des petits ciscos arctiques et sardinelles en provenance du fleuve Colville peut être retardée ou bloquée par la digue West Dock pendant les périodes de vents d'est violents et persistants du début de la saison. La digue Endicott semble avoir peu d'effets sur le petit cisco arctique des fleuves Colville et Sagavanirktok et sur le cisco sardinelle du Colville.

En ce qui concerne l'habitat des poissons, les chaussées sur digue auraient pour effet principal de tenir les poissons à l'écart de leurs aires d'alimentation préférées. Les digues West Dock et Endicott semblent avoir peu d'effets sur l'habitat d'alimentation des gros ombles chevalier, corégones tschir, ciscos arctiques et cisco sardinelles ou des petits ombles de l'Arctique et corégones tschir. Cependant, la digue West Dock pourrait empêcher les petits ciscos arctiques et sardinelles d'atteindre 30 p. 100 environ de leur habitat d'alimentation d'été préféré.

La question fondamentale à se poser est de savoir si les chaussées sur digue affectent ou non les populations des espèces anadromes. Les digues West Dock et Endicott ne semblent pas constituer une menace pour les populations d'omble chevalier et de corégone tschir dans cette région. Bien que la digue West Dock puisse bloquer le passage du petit cisco sardinelle, il n'y a que 5 p. 100 environ des ciscos sardinelles du fleuve Colville de cette classe de taille qui se déplacent assez loin vers l'est pour en être affectés, de sorte que cette digue n'aurait probablement pas de répercussion sur cette population. Le cas du cisco arctique est plus complexe. Si les ciscos arctiques d'âge 0+ qui migrent vers les eaux de l'Alaska en provenance du Mackenzie constituent une partie importante de la population du Mackenzie, ou s'ils n'appartiennent qu'à un seul et même stock du Mackenzie plutôt qu'un mélange de stocks, il est possible que la population du cisco arctique soit perturbée.

Partie 2 : Effets possibles de chaussées sur digue aux pointes King et Stokes le long du littoral du Yukon

Deux sites d'exploitation possibles ont été choisis le long du littoral du Yukon, soit les pointes King et Stokes. Le projet de la pointe King prévoit la construction d'une chaussée sur digue remblayée pleine ainsi que d'un brise-lames, et celui de la pointe Stokes, d'une chaussée sur digue remblayée pleine et d'un chenal dragué.

Les conditions océanographiques observées aux pointes King et Stokes varient beaucoup en fonction du temps, particulièrement par vents d'est, en raison de la présence du panache du fleuve Mackenzie.

Les effets possibles des digues proposées sur les conditions océanographiques locales aux deux endroits sont analogues. Par vents d'est, le transport vers l'ouest d'eau saumâtre chaude serait interrompu et des fosses d'eau froide saline se formeraient à l'ouest de ces ouvrages. Les conditions du milieu seraient beaucoup moins modifiées par vents d'ouest.

Des études antérieures ont révélé qu'environ 87 p. cent des prises totales dans cette région sont composées de ciscos arctiques, de ciscos sardinelles et d'ombles chevalier; cependant, seuls les circos arctiques et sardinelles s'y trouvent en abondance. Une étude de la pêche au verveux dans la baie de Phillips indique que les petits (LF < 250 mm) circos arctiques et sardinelles sont les groupes les plus nombreux dans cette région pendant la saison des eaux libres. C'est pourquoi les ciscos arctiques et sardinelles ont été choisis comme espèces dignes.

Il est improbable que les ouvrages proposés aux pointes King et Stokes aient des effets sur les gros ciscos arctiques et sardinelles, compte tenu des dimensions relativement petites de ces ouvrages et des capacités de déplacement de ces gros individus. Cependant, la situation des petits ciscos arctiques et sardinelles est plus complexe, étant donné qu'il n'y a pas suffisamment de données sur les répartitions et les déplacements de ces groupes pour déterminer les répercussions des ouvrages proposés.

Les effets sur les populations de cisco sardinelle et de cisco arctique dépendraient du pourcentage des stocks du Mackenzie de chacune de ces espèces qui empruntent les eaux littorales du Yukon, ou de leur origine, à savoir s'ils proviennent d'un stock unique ou mixte. La réponse à ces questions n'est pas encore connue.

Partie 3 : Pertinence des données disponibles et insuffisance sérieuse de données sur les chaussées sur digue au Yukon

Il n'y a pas suffisamment de données physiques disponibles pour permettre d'établir comment les ouvrages proposés aux pointes King et Stokes modifieront les masses d'eau. Pour remédier à cette situation, il faudrait recueillir quotidiennement à chacun des emplacements, pendant la saison des eaux libres, des données océanographiques et météorologiques. Ces données devraient être recueillies suivant un quadrillage allant du littoral à 3 km au large, et s'étendant sur 5 km environ de chaque côté des aménagements proposés. De plus, l'appareil de cartographie thématique à très haute définition du satellite Landsat pourrait être utilisé pour déterminer les caractéristiques océanographiques de la zone littorale.

Le principal problème auquel il a fallu faire face, relativement aux programmes de surveillance en Alaska, est le manque de données locales sur les pêches avant la construction, auxquelles comparer les résultats des études en cours. Il n'existe aucune donnée sur les pêches saisonnières pour les emplacements spécifiques des aménagements proposés. Bien que des données saisonnières aient été recueillies en 1985 sur la pêche au filet maillant et à la seine ainsi que des données quotidiennes en 1986 sur la pêche au verveux dans la baie de Phillips, située entre les pointes King et Stokes (c'est-à-dire baie peu profonde avec apport fluvial), cet endroit est suffisamment différent pour qu'il soit difficile d'extrapoler les résultats aux emplacements à l'étude.

Pour remédier à l'insuffisance de données, il faudrait recueillir pendant un certain nombre d'années des données de base sur les pêches et s'assurer également d'avoir des renseignements sur les divers régimes de vent afin de tenir compte de la variabilité naturelle au sein du système.

Il faudrait notamment entreprendre des programmes de marquage-recapture qui fourniraient des renseignements détaillés sur les configurations de la répartition et sur les déplacements en fonction du temps. Des données sur l'âge et la longueur et sur la longueur par rapport au poids, en particulier des petits ciscos arctiques et sardinelles, recueillies pendant un certain nombre d'années, à l'emplacement des aménagements proposés et à des emplacements éloignés, pourraient être utilisées pour déterminer les modifications à l'habitat causées par la présence des chaussées sur digue.

Deux questions les plus importantes qui demeurent sans réponse sont les suivantes : (1) Quel est le pourcentage de ciscos arctiques du Mackenzie qui migrent vers l'Alaska ? (2) Les poissons proviennent-ils d'un stock unique ou d'un mélange de stocks ? Les études qui seront entreprises dans l'avenir devraient être conçues de manière à recueillir les données nécessaires pour répondre à ces deux questions. Il s'agirait notamment de réaliser des études par marquage-recapture, des études de comparaison des prises réalisées simultanément des deux côtés du delta du Mackenzie et des études de séparation des stocks.

PART 1: EFFECTS OF CAUSEWAYS ON ANADROMOUS FISH POPULATIONS IN THE ALASKAN BEAUFORT SEA

INTRODUCTION

The construction of the first solid-fill causeway in the Prudhoe Bay region of Alaska during 1973 raised concern among regulatory agencies about the effects these structures might have on anadromous fish populations. Prior to the start of causeway construction, the study of Arctic fishes had focused more on the freshwater systems of northern Alaska and Canada than on the nearshore coastal zone of the Beaufort Sea. Although the previous investigations provided a general understanding of the life histories of many anadromous and freshwater fish species, they were of little direct use in assessing the effects of solid-fill causeways on the nearshore environment. The few studies that detailed seasonal distribution, movements and trophic relationships of anadromous species in the coastal zone had been conducted in areas where no causeways existed or were planned.

Beginning in 1981, and continuing to the present, intensive fisheries monitoring studies have been conducted in the Prudhoe Bay/Sagavanirktok Delta region as part of a regulatory agency directed program to determine the effects of solid-fill causeways on movement patterns and habitat utilization of anadromous fish. This section of the present report reviews and synthesizes the results of these studies, and provides specific analyses using the computerized fish database to determine the potential impacts on anadromous fish of the causeways in the Prudhoe Bay/Sagavanirktok Delta region.

STUDY AREA

The overall area of concern for this synthesis is the 150-km long segment of the Alaskan Beaufort Sea coast between the Colville and

Sagavanirktok rivers (Fig. 1). These rivers are the largest and second largest drainages on the Alaskan North Slope, respectively, and are the region's major source of freshwater discharge. The coastal zone is characterized by shallow bays, river deltas, and an extensive barrier island-lagoon system that extends from the western edge of Prudhoe Bay to Oliktok Point. The barrier island-lagoons, Prudhoe Bay and the delta shoals that extend seaward for 3-4 km from both river mouths, are generally shallow (< 2 m) in depth. Seaward of the barrier islands, water depths increase to 2-3 m within 50 m from shore. Prudhoe Bay proper is partially protected from the influence of offshore marine waters by a series of shallow shoals along its seaward margin.

The shallow nearshore zone (<2 m in depth) is a biologically important feature of the region during summer because it is generally warmer and less saline than offshore marine waters (temperature: 5-10 ^{o}C vs -1 to 3 ^{o}C; salinity: 10-25 ppm vs 27-32 ppm, respectively). This relatively narrow band of water (2-10 km in width) is believed to be the principal feeding habitat for the anadromous fish that summer in the Beaufort sea and overwinter in North Slope coastal drainages (Craig 1988); thus, it has been the focal point of intensive biological monitoring studies.

HISTORY OF CAUSEWAY CONSTRUCTION

The development of onshore oil and gas production facilities in the vicinity of Prudhoe Bay, Alaska, has involved some modification of coastal features. Offshore islands have been enlarged, and in some cases artificial islands have been constructed to accommodate drilling activities. The most extensive alterations, however, have resulted from the construction of causeways which extend varying distances into the nearshore environment. Since 1973, four solid-fill and/or breached causeways have been completed, and two others are presently under consideration (Fig. 2).

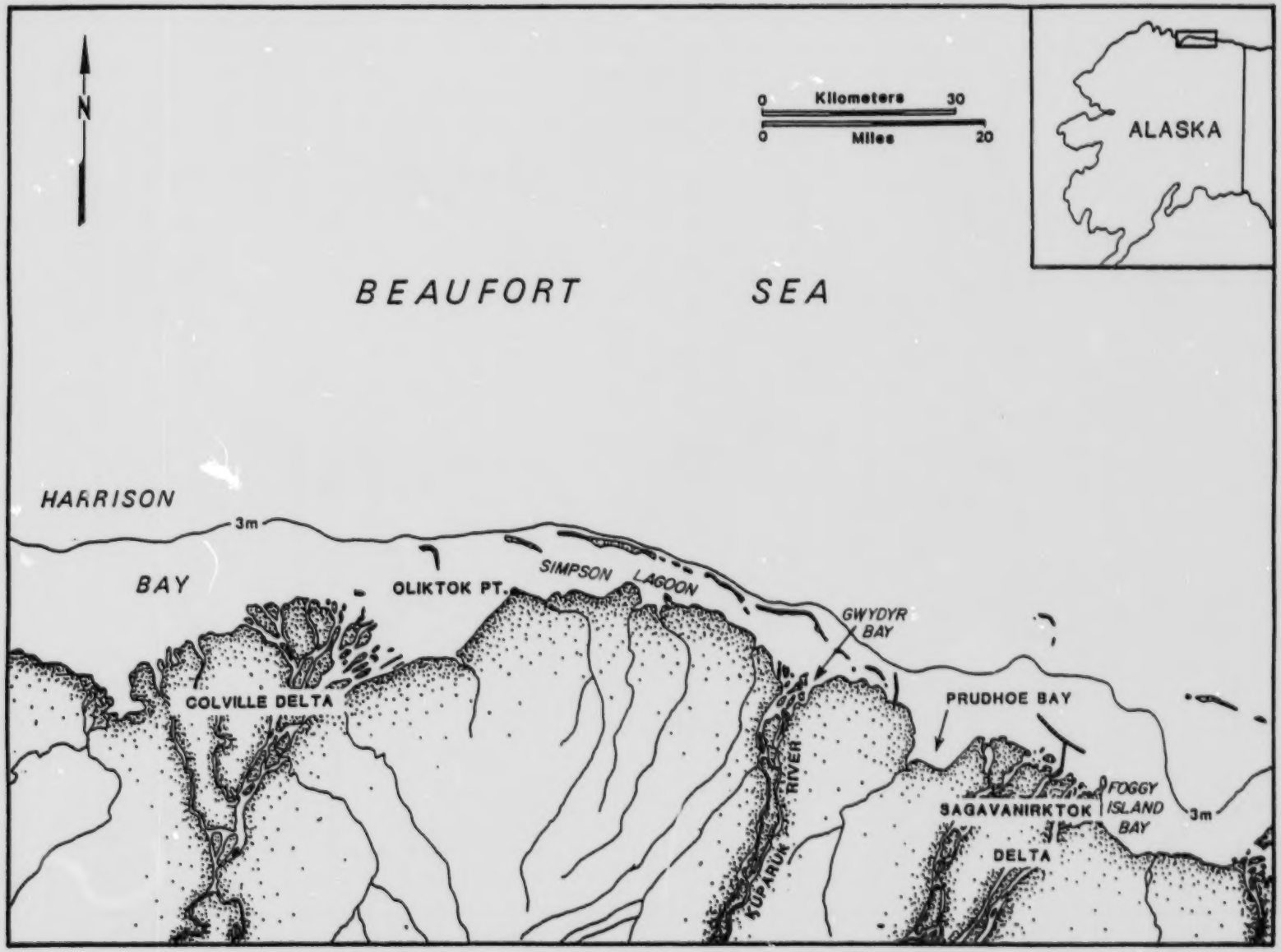


Figure 1. Central Alaskan Beaufort Sea coast.

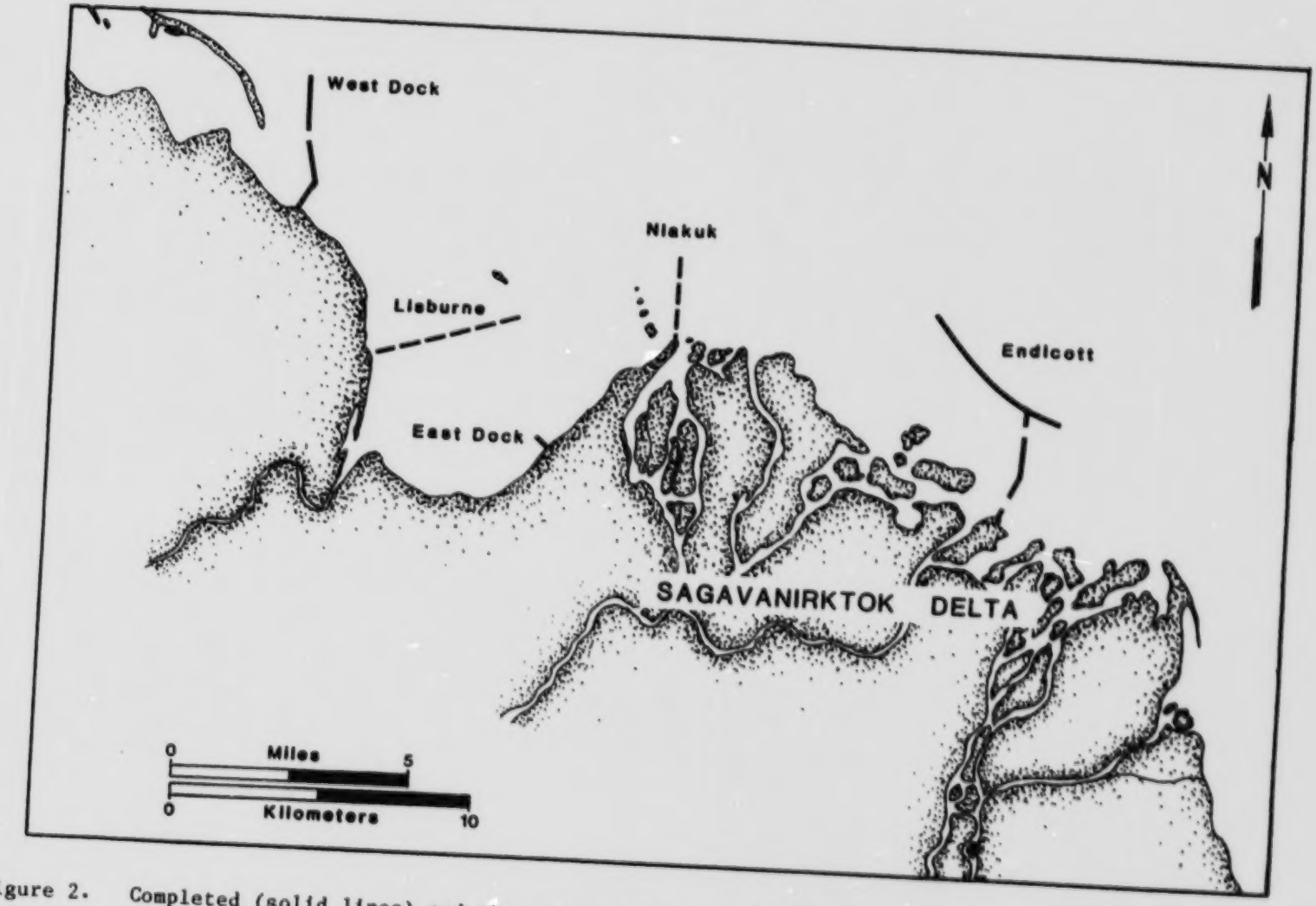


Figure 2. Completed (solid lines) and the proposed (dashed lines) solid-fill and breached causeways in the Prudhoe Bay/Sagavanirktok Delta area. Breaches in West Dock and Endicott causeways are not drawn to scale.

The first solid-fill structure, known as East Dock, was constructed in 1973 along the southeastern shoreline of Prudhoe Bay (Fig. 2). This 400-m long gravel jetty was built to facilitate the off-loading of oilfield materials and supplies from shallow draft barges. The need to off-load larger deeper draft barges led to the construction of a 1.3 km long solid-fill causeway on the northwest side of Prudhoe Bay in 1975 (Fig. 2). This causeway, known as West Dock, was extended to a length of 2.8 km in 1976 to allow for the off-loading of massive housing modules weighing in excess of 100 tons that were required to complete the production facilities in Prudhoe Bay. In 1981, West Dock was extended another 1.1 km (Waterflood Extension) in order to gain access to the relatively sediment-free water from deeper, offshore areas. This water was for injecting into the Prudhoe Bay oil fields to enhance production. A 15.2-m wide breach was installed at the base of the Waterflood Extension to permit fish passage.

In 1983, a 300-m long solid-fill causeway was constructed at Oliktok Point on the eastern side of the Colville River delta (Fig. 1). This causeway served as a dock to off-load all the production equipment used in the development of the Kuparuk oil field, located west of Prudhoe Bay.

The largest causeway to date, the Endicott Causeway was constructed off the Sagavanirktok River delta in 1985 (Fig. 2). It consists of two segments; a 5-km long solid-fill section connecting two offshore artificial islands (interisland causeway), and a 3.1-km segment extending from the Sagavanirktok River delta to the interisland causeway. The shore-to-interisland segment contains two breaches to allow for fish passage; a 61-m wide breach near the delta, and a 152-m wide breach near the interisland causeway junction.

Two other causeways, known as Lisburne and Niakuk, have been proposed in the Prudhoe Bay area (Fig. 2). The Niakuk causeway, which is presently in the feasibility stages of planning, would be located near the western edge of the Sagavanirktok River delta. Plans to

construct the Lisburne causeway within Prudhoe Bay appear to have been abandoned in favor of shore-based, slant-drilling operations.

PHYSICAL PROCESSES

Hydrographic conditions in the nearshore waters of the Alaskan Beaufort Sea are influenced by a complex mixture of physical factors including air temperature, wind velocity and direction, precipitation, ice cover, river discharge, and solar radiation (Gilbertson et al. 1987; Savoie and Colonell 1988). The physical environment (e.g. water temperature, salinity, current, etc.) in turn, influences the movement, distribution, and habitat use of anadromous and marine fishes along the coast (Moulton et al. 1986; Gilbertson et al. 1987). The following sections summarize the major physical processes that control hydrographic conditions in the Prudhoe Bay/Sagavanirktok region and include discussions of the effects of West Dock and Endicott causeways on these processes.

Seasonal Ice Cycle

The nearshore zone is dominated by land-fast ice for approximately nine months of the year. With the advent of cold air temperatures in late September to early October, ice begins to form along the mainland shore and around the barrier islands. As winter progresses, ice thickness increases at a rate of about 1 cm/day, so that by February, areas that are less than 2 m in depth are frozen to the bottom.

Breakup begins in early-June when freshwater river discharge flows over the land-fast ice. The combined effects of overflow water and solar radiation weakens the land-fast ice until cracks and holes form in its surface. Melt-water then drains beneath the ice causing it to lift off the bottom and float to the surface. Under the action of sun, wind, and waves, the ice deteriorates rapidly and by mid- to late July nearshore waters are essentially ice-free. Except for periodic

intrusions of wind-borne pack ice, the nearshore waters remain ice-free until freeze-up begins again in September.

Seasonal Hydrographic Cycle

Warming air temperatures during spring cause extensive ice and snow melt in the mountains and coastal plains of northern Alaska. This relatively warm fresh water is discharged into the nearshore zone where it enhances breakup and initially establishes the low-salinity band of water that forms in the nearshore zone. Partial ice cover during the early stages of breakup minimizes mixing between nearshore and offshore marine-water masses, and helps to maintain the integrity of the brackish band of water along the coast.

By mid-July, the combination of solar heating, wind and continued river runoff causes nearshore ice to dissipate, resulting in a warming of nearshore surface waters. This is particularly true for the areas within the barrier lagoons and off the river deltas.

Precipitation (i.e., snow and rain) during the open-water season periodically increases the amount of fresh water entering the nearshore zone. Winds cause mixing of the various water masses and generates currents that transport these water masses along the coast. Depending on their direction, speed and duration, the winds can also transport surface waters offshore and cause cold subsurface offshore marine water to intrude into shallow nearshore areas.

As the open-water season progresses, declining river discharge reduces the input of warm fresh water into the coastal region, and the influence of offshore marine water becomes more dominant. By early to mid-August, the decreased flow of river water is insufficient to counter the effects of the colder marine offshore waters and the nearshore environment becomes colder and more saline, although areas of warm brackish water persist around river deltas. Conditions continue to become colder until ice begins to form in late September or early October.

Local Physical Processes and the Role of Causeways

Although the general mechanisms that control nearshore oceanography are fairly well understood, it is difficult to predict the effects of any one factor, since overall conditions depend upon the complex interaction of many variables (Savoie and Colonell 1988). Despite these limitations, intensive physical oceanographic studies conducted during monitoring programs for the West Dock and Endicott causeways have provided sufficient data to determine general oceanographic patterns on a localized basis (Savoie and Wilson 1983, 1984, 1986; Hachmeister et al. 1987; Gilbertson et al. 1987; Short et al. 1987; Savoie and Colonell 1988).

Wind-driven currents dominate the shallow nearshore waters of the Beaufort Sea. Northeasterly and northwesterly winds prevail throughout the summer. Changes in wind direction can elicit rapid shifts in nearshore current flow within a matter of hours. Northeast winds typically cause an offshore transport of surface water that is partially counter-balanced by an onshore flow of subsurface marine water (Fig. 3). The net effect is a lowering of water levels along the coast (negative surge) and intrusions of cold marine bottom water to within the 2-m contour; these waters tend to be at 0 ^{o}C and have salinities >25 ppt. Northwesterly winds generally cause a down-welling along the coast which forces bottom marine water offshore and enables warm brackish water to build up in nearshore areas (positive surge). The integrity of the warm, brackish nearshore zone is thus highly dependent on wind periodicity and speed. Northwesterly winds help maintain the nearshore habitat by preventing the intrusion of offshore marine water and inhibiting the transport of warm, low-salinity nearshore water to offshore areas. Northeasterly winds have the opposite effect.

Northeast Winds

During northeast winds, offshore water flows from east to west (Fig. 4). Under these conditions most of the fresh water from the Sagavanirktok

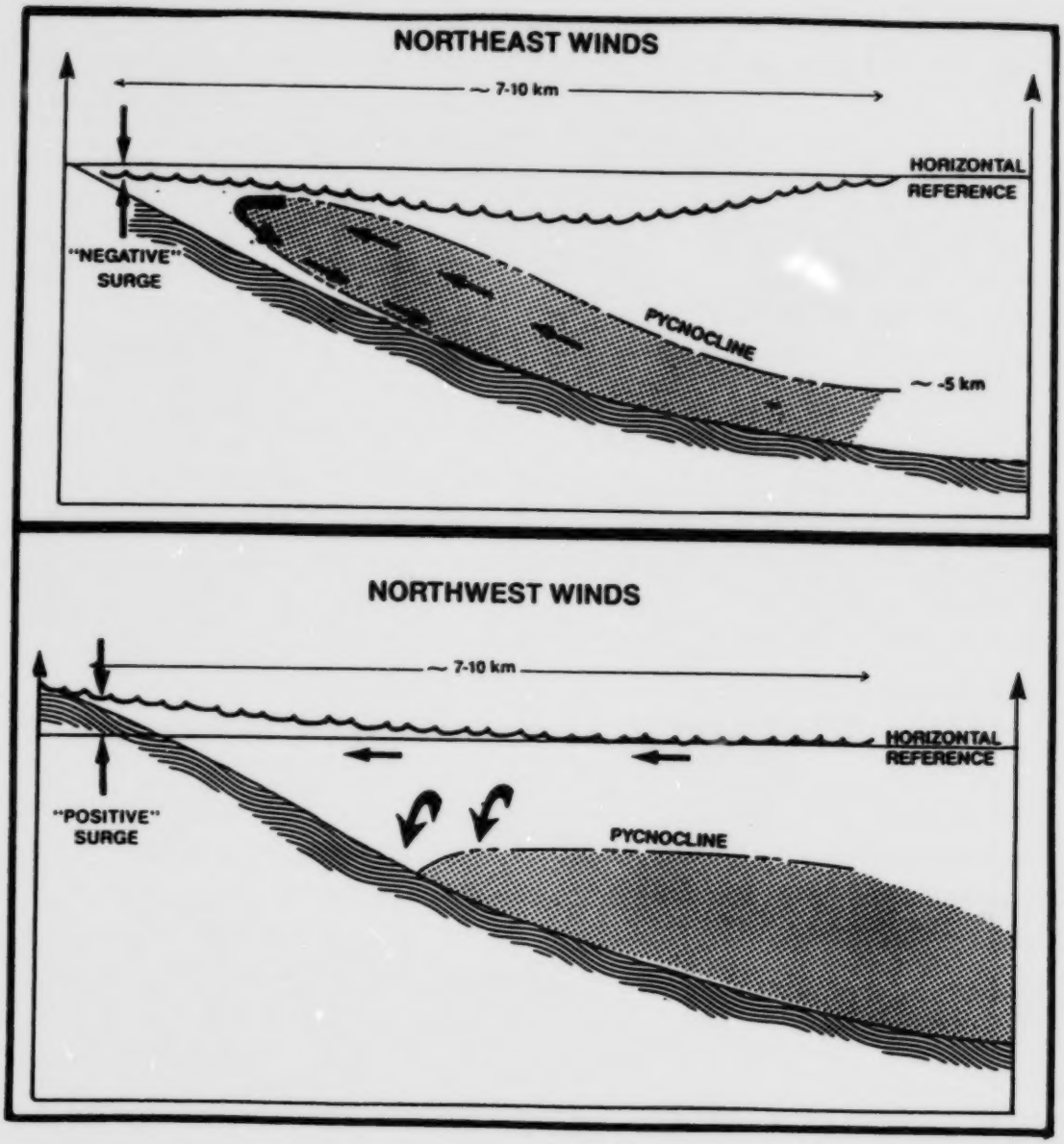


Figure 3. Representation of water mass movements under northeast and northwest wind conditions. Shaded area under pycnocline represents cold, saline water.

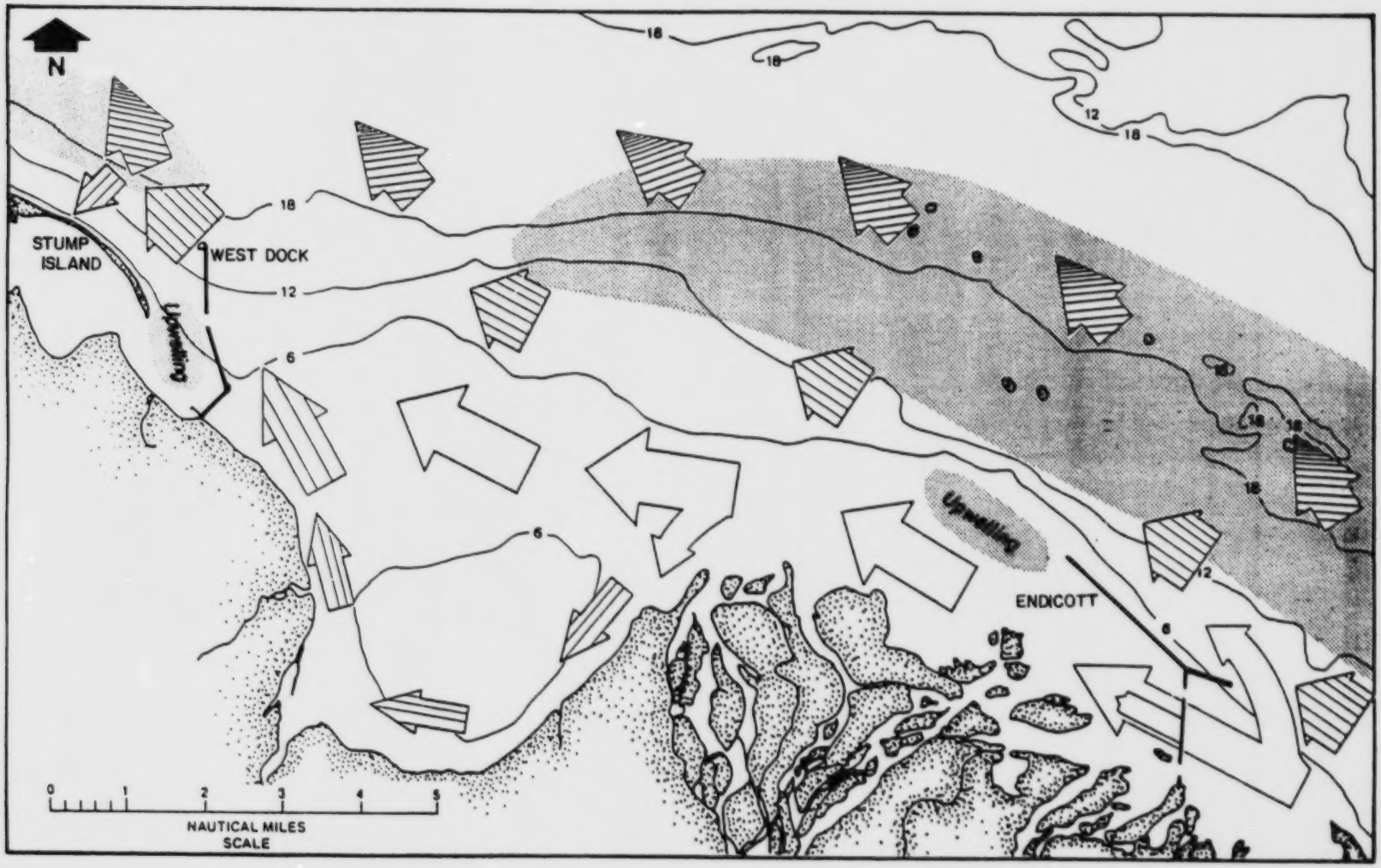


Figure 4. Generalized circulation patterns under strong northeasterly winds. The shading of arrows represent the relative salinities of the surface water masses. The stippled areas represent upwelled cold, saline water (adapted from Hachmeister et al., 1987).

River is deflected westward, while a minor component is deflected offshore. The associated onshore movement of marine bottom water, coupled with local bathymetric features, creates areas of intense upwelling just offshore from the Endicott causeway. The presence of the causeway itself results in a small area of upwelling just west of its seaward tip (Fig. 4).

The Sagavanirktok River plume is one of the dominant factors determining the hydrographic character of Prudhoe Bay. Mixing of upwelled marine water and fresh water from the Sagavanirktok River creates a warm, brackish, buoyant plume that passes across Prudhoe Bay and accumulates on the east side of the West Dock causeway. It is then deflected, first northward then westward around the tip of the causeway and along the ocean side of the barrier islands. Physical conditions in Prudhoe Bay also depend upon the degree of mixing, the rate of river discharge, the prior temperature and salinity characteristics of the coastal water mass, and the exact nature of prevailing winds (velocity and direction).

West of West Dock causeway, the onshore movement of marine bottom water causes cold, saline water to enter the lagoon system through the barrier island channels. The marine intrusion immediately west of West Dock is enhanced by the presence of the causeway. Deflection of longshore currents at the tip of West Dock creates a vortex that results in strong upwellings of marine water (Fig. 4). As will be discussed later, such features have important ramifications regarding the impact of solid-fill causeways on anadromous fish habitat.

Northwest Winds

Westerly and northwesterly winds deflect the Colville and Kuparuk river plumes causing warm, brackish water to flow eastward through the lagoon complex and out through the barrier island channels. Water flowing past Stump Island is deflected north and then eastward around the tip of the West Dock causeway (Fig. 5). Flow divergence at the tip of West Dock causes an upwelling along the east side of the structure; however, the

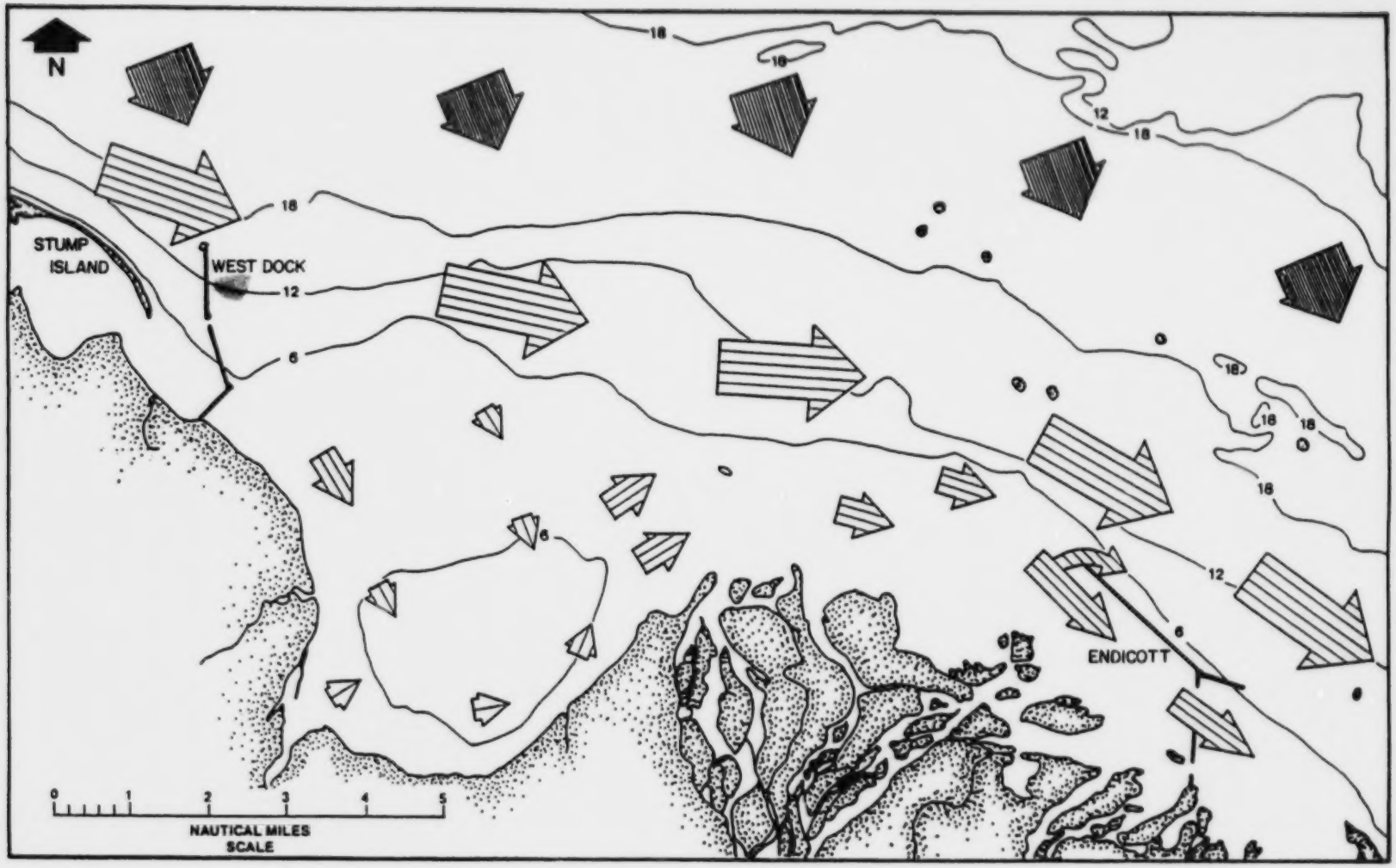


Figure 5. Generalized circulation patterns under strong northwesterly winds. The shading of arrows represent the relative salinities of the surface water masses. The stippled areas represent upwelled cold, saline water (adapted from Hachmeister et al., 1987).

intensity of this upwelling is less than that which occurs west of the causeway during easterly winds. This occurs because bottom marine water moves onshore during easterly winds and offshore during westerly winds. Upwelled water thus tends to be colder and more saline during periods of east winds.

In the vicinity of the Endicott causeway, northwest winds cause both nearshore and offshore waters to flow to the east. This brackish "nearshore stream" merges with the plume from the east channel of the Sagavanirktok River and continues eastward. Since bottom marine water is pushed offshore during westerly winds, there are no areas of major marine upwelling during northwest winds (Fig. 5).

BIOLOGICAL SETTING

The following description of the biological environment is primarily based on the results of the fish monitoring programs conducted between 1981 and 1986. In all cases the primary sampling gear has been the fyke net; a passive trap net that intercepts fish as they move. Gill nets have been used on a limited basis, especially in spring when ice conditions do not permit the setting of fyke nets.

General Description of Fish Community

Between 1981 and 1986, 34 species or groups of fish have been reported from fyke net catches in the Prudhoe Bay/Sagavanirktok Delta region. Twenty-eight of these have been identified to species, while the remaining six were identified to genus (Table 1). Although the number of species varied considerably among years (high 24; low 14), these differences probably reflect the duration and timing of the individual studies and the placement of fyke nets, rather than real changes in species composition. The studies that reported the highest number of species typically were of the longest duration and had more nets located in offshore waters. Of principal interest is the fact that during each of the six years, two marine (Arctic cod and fourhorn sculpin) and four

Table 1. Species composition (percent) of fish caught in fyke nets in the Prudhoe Bay/Sagavanirktok Delta area from 1981 through 1986[1]. * No specific species.

Species	Year						
	81	82	83	84	85	86	Frequency[2]
Freshwater/Anadromous							
Arctic cisco	15	29	11	6	29	11	6
Least cisco	7	2	2	7	5	<1	6
Arctic charr	2	5	3	3	6	1	6
Broad whitefish	<1	6	3	3	3	<1	6
Humpback whitefish	<1	<1	<1	<1	<1	<1	6
Round whitefish	<1	<1	<1	<1	<1	<1	6
Inconnu (Sheefish)	<1	-	-	-	-	-	1
Pink salmon	<1	<1	-	<1	<1	<1	5
Chum salmon	<1	-	-	<1	-	<1	3
Chinook salmon	<1	-	-	<1	-	-	2
Coho salmon	<1	-	-	-	-	-	1
Arctic grayling	<1	<1	<1	<1	<1	<1	6
Ninespine stickleback	<1	<1	<1	<1	<1	<1	6
Threespine stickleback	<1	-	-	-	-	<1	2
Burbot	<1	<1	-	<1	-	<1	4
Boreal (Rainbow) smelt	<1	<1	1	<1	<1	<1	6
Slimy sculpin	-	<1	-	<1	<1	<1	4
Marine							
Arctic cod	49	28	49	52	25	74	6
Fourhorn sculpin	24	28	30	26	28	9	6
Northern daddy sculpin	-	-	-	<1	<1	<1	3
Ribbed sculpin	-	-	-	<1	-	-	1
Saffron cod	1	<1	<1	2	<1	<1	6
*Greenling	-	-	-	-	-	<1	1
*Snailfish	<1	<1	<1	<1	<1	-	5
Capelin	<1	-	-	<1	<1	<1	4
Sandlance	-	-	<1	<1	<1	<1	4
*Blenny	-	-	-	-	<1	-	1
*Eelpout	-	-	-	-	<1	-	1
*Prickleback	<1	<1	-	-	-	<1	3
Pacific herring	<1	<1	-	<1	<1	<1	5
Wolf-eel	-	-	-	-	-	<1	1
Arctic flounder	<1	<1	<1	<1	<1	<1	6
Starry flounder	-	-	-	-	-	<1	1
Total number of identified species	22	17	14	23	19	24	

1 Data for 1981 Griffiths and Gallaway (1982); for 1982 Griffiths et al. (1983); for 1983 Woodward and Clyde (1983); for 1984 Moulton et al. (1985); for 1985 Cannon et al. (1987a); for 1986 Glass et al. (1986).
2 Frequency of occurrence over the six-year period.

anadromous species (Arctic and least cisco, Arctic charr and broad whitefish) have accounted for between 95 and 98% of all fish taken by fyke net (Table 1).

The objectives of this study were to concentrate our efforts on fish that are important to local human populations. Consequently, we have concentrated on the four anadromous fish species: Arctic cisco (Coregonus autumnalis), least cisco (C. sardinella), Arctic charr (Salvelinus alpinus), and broad whitefish (C. nasus).

Anadromous Fish Feeding Cycle

Although the life-history, migration, and distribution patterns of each Arctic anadromous species are somewhat different, there are some general trends among the species. All species spend approximately 9 months in overwintering areas in the rivers and estuaries, and then move downstream and disperse into nearshore coastal waters during the ice-free season (Craig 1988). The primary purpose of this movement appears to be to exploit the abundant food resources found in nearshore waters. Individual species and the various size-classes forage in coastal waters for differing lengths of time but nearly all vacate the region prior to freeze-up, and return to overwintering areas.

The summer feeding dispersal is viewed as a critical facet in the overall success of anadromous populations. In the Arctic, most of the yearly growth of anadromous fish is achieved during summer, particularly during the first half of the season (Griffiths and Gallaway 1982; Moulton et al. 1986; Gilbertson et al. 1987). In addition, fish which are unable to accumulate sufficient fat reserves during summer may be less likely to survive the long winter (Schmidt et al. 1988). The importance of the relatively short open-water season has led to the extensive environmental studies that have been conducted in the Prudhoe Bay/Sagavanirktok area during this period. It is thought that any disruption of summer feeding by anadromous fish could have substantial consequences to the overall success of the populations.

Throughout the following discussions there is frequent use of the terms small (<250 mm FL) and large (>250 mm FL) fish; FL refers to fork length. These terms were originally based upon different marking techniques in that fish less than 250 mm were thought to be too small to carry a Floy tag and were marked in some other fashion (e.g. freeze branding, dye marking etc.). This convention has been adhered to within the Prudhoe Bay/Sagavanirktok Delta biological reports. Although our discussion will at times focus on specific size cohorts, the "small fish/large fish" designation is maintained in the present report for clarity and simplicity.

Sources of Key Species

Arctic cisco

Spawning grounds for Arctic cisco have been located only in the Mackenzie River system (Fig 6). It has been postulated that the Arctic cisco found in Alaskan waters are migrants from Canada (Gallaway et al. 1983; Bickham et al. 1988; Table 2). These authors suggest that young-of-the-year (y-o-y) fish are transported down the Mackenzie River, and then at least a portion of the population is transported to the west by prevailing nearshore currents. Within Alaska they take up residence in some of the larger rivers (e.g. Colville and Sagavanirktok rivers) and use coastal waters for summer feeding. Fish remain in Alaska until the onset of sexual maturity, at which point they return to the Mackenzie River system to spawn. Some support for this hypothesis was obtained in 1985 when a westward movement of age 0^+ (y-o-y) Arctic cisco was apparently documented by the successive appearance of this age group starting in Canada and moving west along the Canadian/Alaskan Beaufort Sea coast (Bond and Erickson 1987; Cannon et al. 1987a; Fawcett et al. 1986).

Evidence of the return spawning migration of 'Alaskan' cisco to the Mackenzie River is provided by opportunistic tag recaptures. To date, nine adult Arctic cisco tagged in the Colville/Sagavanirktok Delta

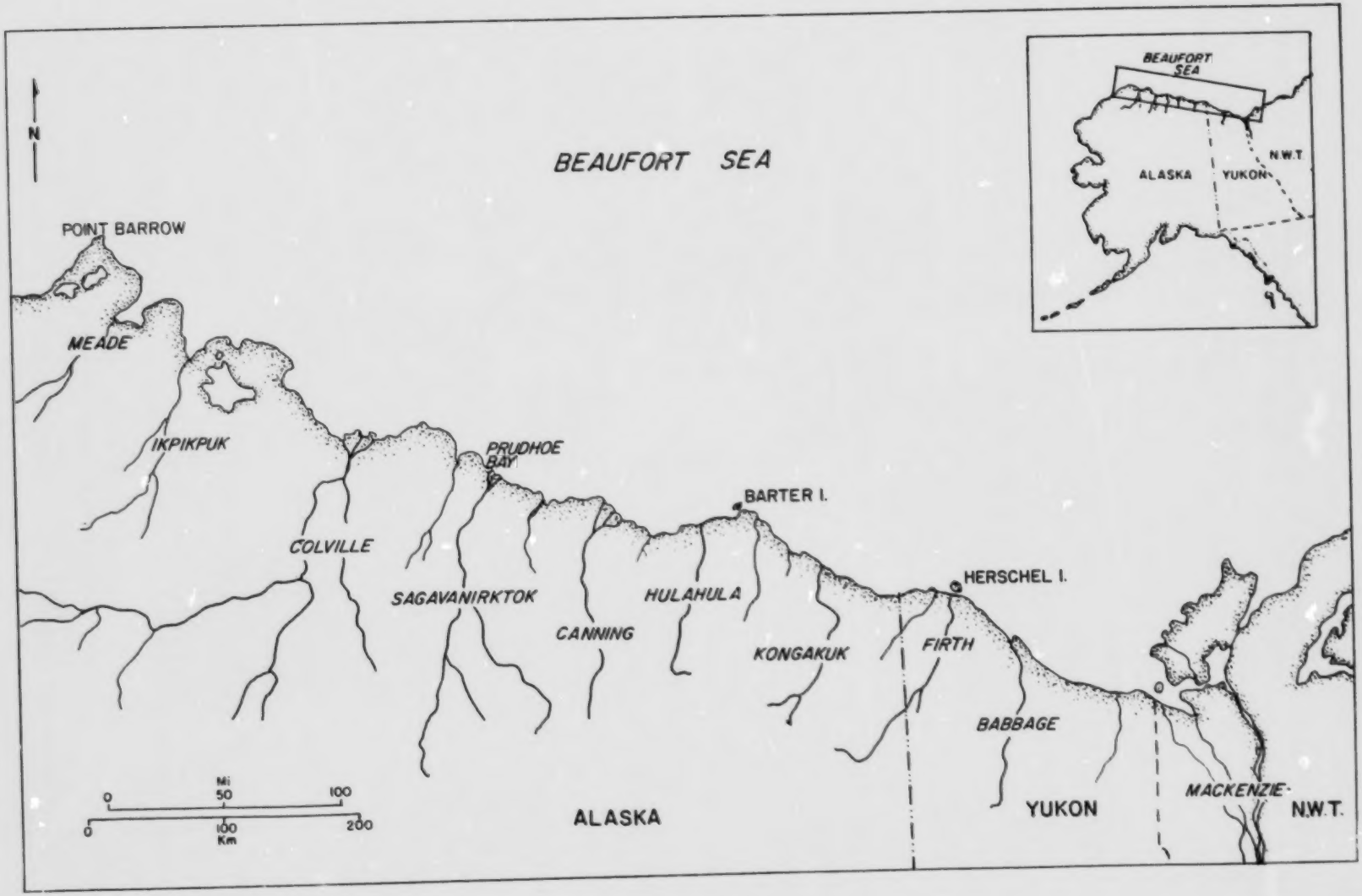


Figure 6. Beaufort Sea coast from Point Barrow, Alaska, to the Mackenzie Delta, Northwest Territories.

Table 2. Principal stocks of important anadromous fishes between the Mackenzie River and Point Barrow, Alaska.

	Arctic Cisco	Least Cisco	Arctic Charr	Broad Whitefish
Mackenzie River to Herschel Island				
Mackenzie	X +	X +	X +	X +
Blow			X	*
Running				*
Deep				*
Babbage			X +	*
Spring			X +	*
Herschel Island to Point Barrow				
Firth			X +	
Malcolm			X	
Fish			X +	
Craig			X	
Kongakut			X +	
Egaksarak			X +	
Aichilik			X +	
Hulahula			X +	
Sadlerochit			X +	
Marsh			X	
Canning			X +	X ?
Shaviovik			X +	
Sagavanirktok	X[a]	*	X +	X +
Putuligayuk			X	
Kuparuk				X
Colville	X[a]	X +	X +	X +
Fish		X o		X +
Ikpikpuk		X o		X o
Oumalik		X o		
Topagoruk		X o		X o
Meade		X +		X +
Inaru		X o		X o

X = utilized for feeding and/or overwintering.
+ = spawning population.
o = probable spawning population.
? = unknown.
* = probable strays, often only a single fish.
a supports overwintering but not necessarily spawning populations (Gallaway et al. 1983).

Sources: McPhail and Lindsey (1970); Alt and Kogl (1973); Scott and Crossman (1973); McCart et al. (1974); Ward and Craig (1974); Kendel et al. (1975); Craig and McCart (1976); Craig (1977); Hablett (1979); Corkum and McCart (1981); Smith and Glesne (1982); Bendock and Burr (1985); Sekerak et al. (1985).

region have been recovered in Canadian waters: one in the Mackenzie Delta (Gallaway et al. 1983), and eight in Phillips Bay (W. Bond, pers. comm., Dept. of Fish. and Oceans, Winnipeg, Canada). The lack of a major recapture effort in Canadian waters has been a major handicap in data acquisition and interpretation.

Emigration of large (>250 mm FL) Arctic cisco from the central Alaskan Beaufort Sea and associated rivers was also suggested from multi-year recapture rates in the Prudhoe Bay region (Table 3). Tag recoveries for least cisco, Arctic charr, and broad whitefish commonly occur up to 5 years after initial tagging. In contrast, returns for Arctic cisco typically cease by their third year at large; the only exception was a single fish tagged in 1982 and recaptured in 1985. These data suggest that, unlike the other three anadromous species, a portion of the Arctic cisco stock leaves Alaskan waters each year.

The same trend has been observed in the commercial gill net fishery operated by the Helmericks family in the lower delta of the Colville River during October and November from 1980 to 1985 (Table 4). The fishery takes large numbers of both least and Arctic ciscoes, and many of these fish carry tags from mark-recapture studies conducted in the Prudhoe Bay/Sagavanirktok Delta area. Moulton and Jennings (1987) observed that tagged least cisco continued to be taken in the fishery up to five years after initial tagging, while the return rates for Arctic cisco decreased to zero by the third year (Table 4). The disappearance of older Arctic cisco from the fishery is consistent with the Mackenzie River spawning hypothesis in that fish apparently leave the Colville River when they approach maturity.

It is thought that age 0^+ Arctic cisco become associated with a particular estuary/freshwater system and remain in close proximity to this area during subsequent summer feeding excursions into the brackish nearshore waters (Griffiths et al. 1983; Fawcett et al. 1986; Gilbertson et al. 1987). As the fish grow larger, they become more euryhaline and extend their summer feeding range along the coast. By the time they are subadults they are found feeding along most of the Alaskan Beaufort Sea coast during the open-water season (Schmidt et al. 1983; Griffiths et al. 1983; Cannon et al. 1987a).

Table 3. Multi-year recapture rates (percent) for large (250 mm) anadromous fish tagged in the Prudhoe Bay area.

Species	Tag Year	Number Tagged	1981	1982	1983	1984	1985
Arctic cisco	1981	1756	0.00	0.17	0.06	0.00	0.00
	1982	874	-	0.46	0.00	0.00	0.11
	1983	0	-	-	-	-	-
	1984	5840	-	-	-	0.62	1.08
Least cisco	1981	6157	1.25	1.01	0.58	1.32	1.61
	1982	3929	-	1.07	1.07	2.42	1.59
	1983	0	-	-	-	-	-
	1984	14126	-	-	-	3.57	4.59
Arctic charr	1981	1054	1.99	1.52	0.47	0.85	0.47
	1982	4389	-	1.06	0.37	1.05	0.75
	1983	0	-	-	-	-	-
	1984	5321	-	-	-	3.29	3.03
Broad Whitefish	1981	122	4.09	0.82	0.82	0.82	1.64
	1982	966	-	1.04	0.72	0.31	0.21
	1983	0	-	-	-	-	-
	1984	2307	-	-	-	3.25	5.98

1981: Griffiths and Gallaway (1982)
1982: Critchlow (1983), Griffiths et al. (1983)
1983: Biosonics (1984), Woodward-Clyde Consultants (1983)
1984: Moulton et al. (1986)
1985: Cannon et al. (1987a)

Table 4. Recapture rates (percent) of Arctic and least cisco tagged in Prudhoe Bay area and recaptured at Helmericks fishery. Data supplied by Moulton and Jennings (pers. comm.).

Species/ Year Tagged	Number Tagged	1980	1981	1982	1983	1984	1985	1986
Arctic cicso								
1980	229	5.90	1.40	0.00	0.00	0.00	0.00	0.00
1981	1756	-	1.90	0.28	0.25	0.00	0.00	0.00
1982	874	-	-	2.86	1.01	0.16	0.00	0.00
1983	0	-	-	-	-	-	-	-
1984	5840	-	-	-	-	1.11	0.61	0.41
1985	11695	-	-	-	-	-	1.12	0.67
Least cisco								
1980	1067	1.90	2.40	0.55	0.59	0.43	0.53	0.41
1981	6157	-	1.90	1.90	1.40	1.30	0.83	0.51
1982	3929	-	-	4.57	1.39	1.41	0.91	0.62
1983	0	-	-	-	-	-	-	-
1984	14126	-	-	-	-	3.30	2.60	2.30
1985	9915	-	-	-	-	-	5.10	2.90

Least Cisco

There are two major spawning regions for anadromous least cisco in the Beaufort Sea: the Mackenzie River system in Canada, and several Alaskan drainages located between the Colville River and Point Barrow (Table 2). Least cisco do not disperse as widely from their natal streams as do Arctic cisco. In Alaska, large (>250 mm FL) Colville River least cisco disperse to the east, at least as far as Foggy Island Bay (see Fig. 1), by early July; few have been reported from as far east as Barter Island (see Fig. 6) (Griffiths et al. 1977; Gilbertson et al. 1987). Smaller fish (<250 mm FL) tend to remain closer to their overwintering drainages. In Prudhoe Bay, the presence of least cisco appears to be a function of the eastward dispersal of the Colville River population. Least cisco generally appear in the region during July, remain in the Prudhoe Bay/Sagavanirktok Delta area for several weeks, and then vacate the area by late August-early September, when they presumably return to spawning and/or overwintering areas in the Colville River or rivers farther west.

Arctic Charr

Arctic charr stocks originate from at least 14 streams between the Mackenzie and Colville rivers (Craig 1988; Table 2). In Alaska, the largest populations are associated with the Sagavanirktok and Canning rivers, while in the Yukon, the Babbage and Firth rivers probably contain the largest stocks (Fig. 6). Unlike the ciscoes, charr spawn and/or overwinter well upstream from the sea in tributaries associated with warm perennial springs (Craig and McCart 1974). Young charr spend as many as four years in fresh water before undertaking seasonal feeding migrations into the Beaufort Sea (Bendock 1979; Craig and Haldorson 1981).

Charr enter the ocean as soon as the rivers breakup (early June), and disperse in the nearshore waters along the coast to feed. Large charr (>250 mm FL) begin returning to spawning and/or overwintering areas as early as late July and early August, while smaller individuals start returning by mid-August. Some non-spawners may remain in the delta regions until mid-September before moving up the rivers (Craig and Haldorson 1981; Griffiths et al. 1983; Moulton et al. 1986; Gilbertson et al. 1987).

Broad Whitefish

In Alaska, broad whitefish stocks are found in several rivers, particularly in those between the Canning River and Point Barrow (Table 2; Fig. 6). To the east the first spawning populations encountered in Canada are associated with the Mackenzie River. They are, however, found in nearshore areas of the Canadian Beaufort Sea (Craig 1988; Table 2). Spawning occurs in the upper reaches of the rivers and/or tributaries, while some overwintering occurs in the delta regions (Kogl and Schell 1974; Bendock 1979; Adams and Cannon 1987; Schmidt et al. 1988).

Typically, broad whitefish do not undertake extensive summer feeding dispersals into the nearshore waters of the Beaufort Sea as do the ciscoes and Arctic charr. In Alaska, only the larger fish (>250 mm) migrate along the coast to feed, while young and juvenile broad whitefish remain close to the deltas during the entire open-water period. In Canada, small Mackenzie River broad whitefish use freshwater systems on the Tuktoyaktuk Peninsula for rearing and overwintering (Bond 1982; Bond and Erickson 1982, 1985). In Alaska, large broad whitefish start moving back into rivers in late-July and early-August, however, small broad whitefish often remain in estuaries until mid-September before moving to overwintering areas (Craig and Haldorson 1981; Griffiths et al. 1983; Moulton et al. 1986; Gilbertson et al. 1987).

Fish Habitat

Habitat Types

There are a wide variety of habitat types along the Alaskan Beaufort Sea coast. Each habitat can be important to one or more anadromous species for one or more reasons including: feeding, overwintering and migrating. Generally, key physical characteristics (i.e., temperature and salinity) of habitats are critical features in determining the importance of the habitat to anadromous fish. Brief descriptions of the important habitat types are given below.

River Deltas and Estuaries

Within river deltas, waters are generally fresh to brackish and warm because of inflow and mixing of warm, fresh water river discharge with colder, marine water from offshore. The amount of estuarine habitat varies with the season, since the river discharge rates change and meteorological conditions alter the water mass conditions. Deltas also act as refugia for anadromous fish during periods of intense marine intrusions.

River Plumes

River plumes are offshore extensions of an estuarine or delta habitat. They provide warm, low salinity waters for extended distances either along shore or offshore. Depending on the meteorological conditions, river plumes afford fish the opportunity to venture away from estuaries and can provide migratory pathways for fish moving along the coast. The seasonal dispersal of least cisco from the Colville River is strongly tied to the westward deflection of the plumes from the Colville and Kuparuk River. Fish can, under continued west winds, by-pass West Dock causeway in conjunction with the plume. Similarly, small Arctic cisco from the Sagavanirktok Delta appear to move west of Prudhoe Bay with the westward moving Sagavanirktok River plume.

Lagoons

Lagoon habitats are partially protected from the direct influence of cold, marine offshore waters by the barrier islands, and thus provide areas of warm, brackish water. They also act as catch basins for the warm, fresh water from river discharge and tundra runoff, and due to their shallow (<2 m) waters they are solar heated during summer.

Despite their protected nature, it is important to note that there is a continuous exchange of water between lagoons and offshore areas. The exchange brings an influx of epibenthic invertebrates that make these areas prime feeding sites for anadromous fish. Griffiths and Dillinger (1981) estimated that a continuous influx of marine epifauna into Simpson Lagoon (west of Prudhoe Bay) was required to provide sufficient prey to support the predators present. Barrier island-lagoons also provide excellent avenues for the longshore dispersal of anadromous fish.

Bays

Bays are similar to lagoons in that they are shallow and somewhat protected from offshore winds. Consequently, waters tend to be warmer due to solar heating and reduced circulation. Factors that determine hydrographic conditions in bays vary with location. For example, Prudhoe Bay is protected by a sill (Gull Island Shoals) that extends along its seaward edge. This sill inhibits marine intrusions and contains warm, brackish water within the bay. Prudhoe Bay is also influenced by discharge from the Sagavanirktok River. In contrast, Foggy Island Bay does not have a sill and is affected more directly by marine water from Stefannson Sound (see Fig. 1). Thus, the warm, low salinity area is confined to shoreline areas.

Ice Edges

Ice edges and the undersurface of ice are areas of high biological activity (Alexander and Cooney 1979). Their role as an important habitat for anadromous fish is most strongly associated with Arctic charr. In the early part of the open-water season Arctic charr are found in the leads adjacent to shore. In this habitat they feed, sometimes extensively, on ice-associated amphipods and other invertebrates. Ice thus represents an important, yet temporary, habitat in nearshore areas.

Importance of Nearshore habitats

The primary advantage of anadromy in the Beaufort Sea appears to be increased feeding opportunities. Craig (1988) reported that the available fish food in the coastal region is an order of magnitude greater, on a per square metre basis, than in freshwater habitats, (approximately 85-90% of the total fish food supply in all habitats combined is in coastal habitats), and that there is far more coastal habitat available. The summer feeding period is extremely important, since, during the nine months of winter feeding by most anadromous species is insignificant (Craig and Haldorson 1981; Schmidt et al. 1988). Numerous studies conducted along both the Canadian and Alaskan Beaufort Sea coasts have shown that charr, ciscoes and whitefish prefer warm brackish water habitats for summer feeding. The degree of preference varies with species and size; however, none of the four anadromous species shows a preference for the cold, marine offshore waters. Thus, loss of preferred feeding habitats could have long term effects on the survival and/or reproductive success of the four anadromous species. However, our understanding of factors that limit Arctic fish populations is rudimentary. It can also be argued that there is an over-abundance of nearshore feeding habitat and that other factors, such as overwintering areas, play a far more important role in regulating fish populations. If this is the case then exclusion of fish from part of their summer feeding habitat could have no significant effect.

Habitat Conditions

In this section we describe the nearshore food web, the important habitat parameters for anadromous fish, and how parameters may be affected by the presence of causeways.

Fish Prey

Nearshore substrates of some lagoon systems are composed of layers of peat. The peat erodes into the nearshore waters through freshwater runoff and extensive bank slumping. It was originally thought that peat was an important source of carbon for the nearshore marine food webs. However, Schell et al. (1982) found that primary production is the principal source of carbon for both the marine and nearshore food webs, although it is augmented by old terrestrial carbon sources (peat) during winter. Freshwater systems depend on algal production and terrigenous modern carbon in summer, and on old terrigenous carbon (peat) during winter (Fig. 7).

In nearshore areas, the food chains leading to fish and birds are short; marine phytoplankton supports epibenthic invertebrates, which in turn are preyed upon by fish, birds, and other vertebrate consumers (Fig. 7). There is a high degree of trophic overlap among vertebrate consumers that is apparently due to the selection of epibenthos over equally abundant infaunal food resources (Craig et al. 1982; Moulton et al. 1986; Cannon et al. 1987b).

Anadromous fish in the Prudhoe Bay/Sagavanirktok River delta area appear to be opportunistic feeders, since their diets vary both among species and within season. For example, when Arctic charr first enter the coastal zone at breakup, their diet consists primarily of the ice-associated amphipod Apherusa glacialis (Griffiths and Dillinger 1981; Cannon et al. 1987b). Once nearshore ice dissipates, charr feed on other marine epifauna and fish. Conversely, the diets of broad

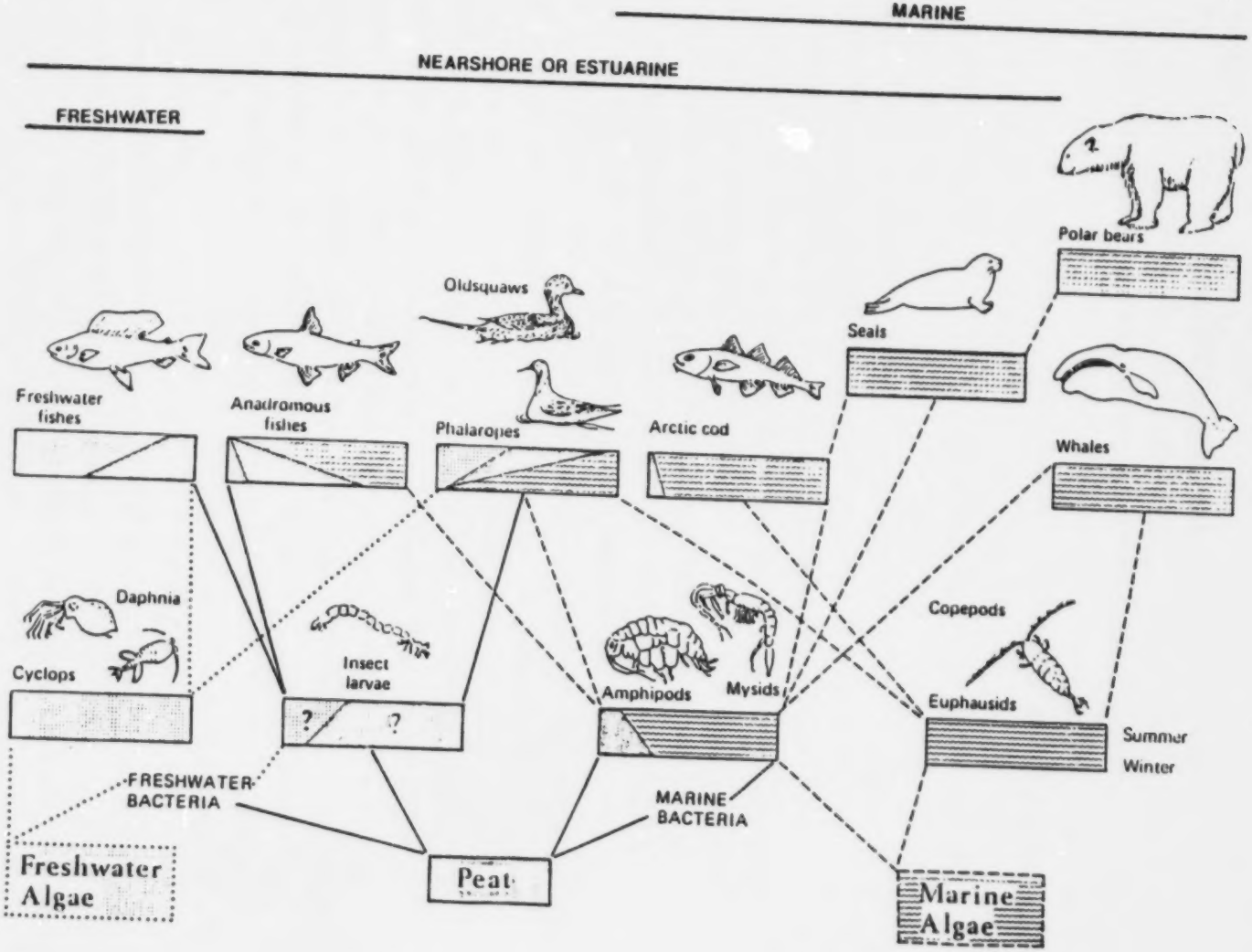


Figure 7. Carbon sources and trophic relationships for Beaufort Sea coastal areas.

whitefish reflect their freshwater preferences in that they consume primarily chironomid larvae throughout the summer season (Moulton et al. 1986; Cannon et al. 1987b). Arctic and least cisco feed primarily on mysids (Mysis litoralis, M. relicta) and amphipods.

Distribution of Fish Prey

Each winter, the water column in the nearshore zone eventually freezes to the bottom within the 2-m contour. Epibenthic fish prey (e.g. mysids, amphipods, isopods etc.) found in shallow coastal regions during summer must repopulate these areas from offshore areas each spring (Feder and Schamel 1976; Griffiths and Dillinger 1981; Feder and McGee 1982; Moulton et al. 1986; Cannon et al. 1987b).

Onshore movement in spring is primarily by passive transport, and appears to be associated with nearshore circulation patterns (Griffiths and Dillinger 1981). In order to maintain prey levels found in the nearshore areas throughout the open-water period, the transport of the prey species must continue throughout the summer (Feder and Schamel 1976; Griffiths and Dillinger 1981). Typically, the onshore flux of prey species and abundance levels show a positive association with salinity (Moulton et al. 1986; Cannon et al. 1987b). Not only is prey biomass higher in more saline areas, but sharp increases in biomass in the nearshore zone often occur in conjunction with sharp increases in salinity. Many of the species in question are associated with pycnoclines, and these interfaces of differing salinities exhibit the highest concentrations of epifauna (Moulton et al. 1986; Cannon et al. 1987b). These data suggest that periodic intrusions of marine water facilitate the onshore transport of epifauna.

Epibenthic prey species that do move inshore, either actively or passively, tend to remain and concentrate near the bottom where current velocities are low (Griffiths and Dillinger 1981). This occurs because (1) areas of low current velocity enable individuals to maintain their position with minimal expenditure of energy, and (2) detritus, primarily peat, tends to settle in areas characterized by low currents (Griffiths

and Dillinger 1981; Truett 1981). Mysids and amphipods often use these detrital deposits for shelter (Griffiths and Dillinger 1981). However, carbon isotope studies indicate that detritus does not play an important role in the feeding ecology of these animals, since isotopically their carbon is marine modern, and not old terrestrial as would be the case if they consumed the detritus either directly or indirectly through an intermediary (Craig et al. 1984). Some epifaunal species may concentrate in the detrital areas in order to feed on other organisms that concentrate there. The amphipod Onisimus glacialis, for example, actively preys upon mysids (Holmquist 1965; Griffiths and Dillinger 1981). Cannon et al. (1987b) speculated that isopods, primarily Saduria entomon, might also concentrate in areas of heavy detrital cover to prey upon other epifaunal species that congregate there.

Water Temperature

Because of its effect on physiological and biochemical mechanisms, water temperature is believed to be one of the most important aspects of habitat. Temperature has a direct effect on growth (Jobling 1981), swimming speed (Fry and Hart 1949), and metabolic rate (Brett 1964; Beamish 1970). Most salmonids, including salmon, trout, charr, ciscoes and whitefish, have optimal growth rates and preferred temperatures, ranging from 12 to 15 C (Brett 1971; Jobling 1981; Fechhelm et al. 1988).

The physiological effects of temperature are believed to be a principal reason why anadromous fish generally remain in nearshore zones during summer. Typically, a relatively narrow band (2 to 10 km wide) of warm water is located along the coast, with the highest temperatures occurring near river deltas and in protected bays and lagoons. A positive association between fish abundance and water temperature has repeatedly been observed in fyke net catches of broad whitefish, least cisco and Arctic cisco in the Prudhoe Bay region; this is particularly true for smaller individuals of each species (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Moulton et al. 1986; Cannon et al. 1987a; Fechhelm et al. 1988).

This is consistent with historical data that shows temperature preferences are higher for juveniles of a species (Ferguson 1958; Coutant 1977). Arctic charr appear to exploit colder, more marine conditions, and studies have shown this species to be more physiologically tolerant of cold (Oesthus 1976; Peterson et al. 1979).

Despite the positive association with water temperature, some anadromous species, particularly least and Arctic cisco, are often more abundant at intermediate temperatures. This trend is believed to reflect a trade off between physiological optima and the trophic requirements of the species. Invertebrate prey tends to be most abundant in colder, more saline areas (reflecting their marine origin) and least abundant in the immediate vicinity of river deltas (optimal temperature zones for fish). Most fish must, therefore, venture into cooler areas in order to feed. An exception appears to be broad whitefish which remain in relatively warm, freshwater areas where they exploit freshwater food sources (e.g. chironomids).

Based upon field-derived temperature preferences of anadromous fish and relative sea surface temperatures interpreted from NOAA-9 polar orbiting satellites, Gallaway et al. (1988) speculated that the warm water habitat along the Beaufort Sea coast between the Canadian border and Harrison Bay consisted of two major units: (1) the Colville/Sagavanirktok River Habitat Unit, and (2) the Mackenzie River Habitat Unit (Fig. 8). A notable feature of the Beaufort Sea coastal warm-water zone is the hiatus that stretches between the mid-point of the Sagavanirktok and Canning river outfalls and a point just east of Kaktovik. The warm water habitats depicted in Figure 8 are most indicative of conditions exploited by least cisco and defines the North Slope distribution of the species.

The preference of anadromous fish for warm conditions should not be construed as being absolute. Arctic cisco are often found in coastal waters during breakup, when nearshore water temperature are still depressed because of ice-melt. Least and Arctic cisco are also found in coastal waters later in the season, after the nearshore zone has become

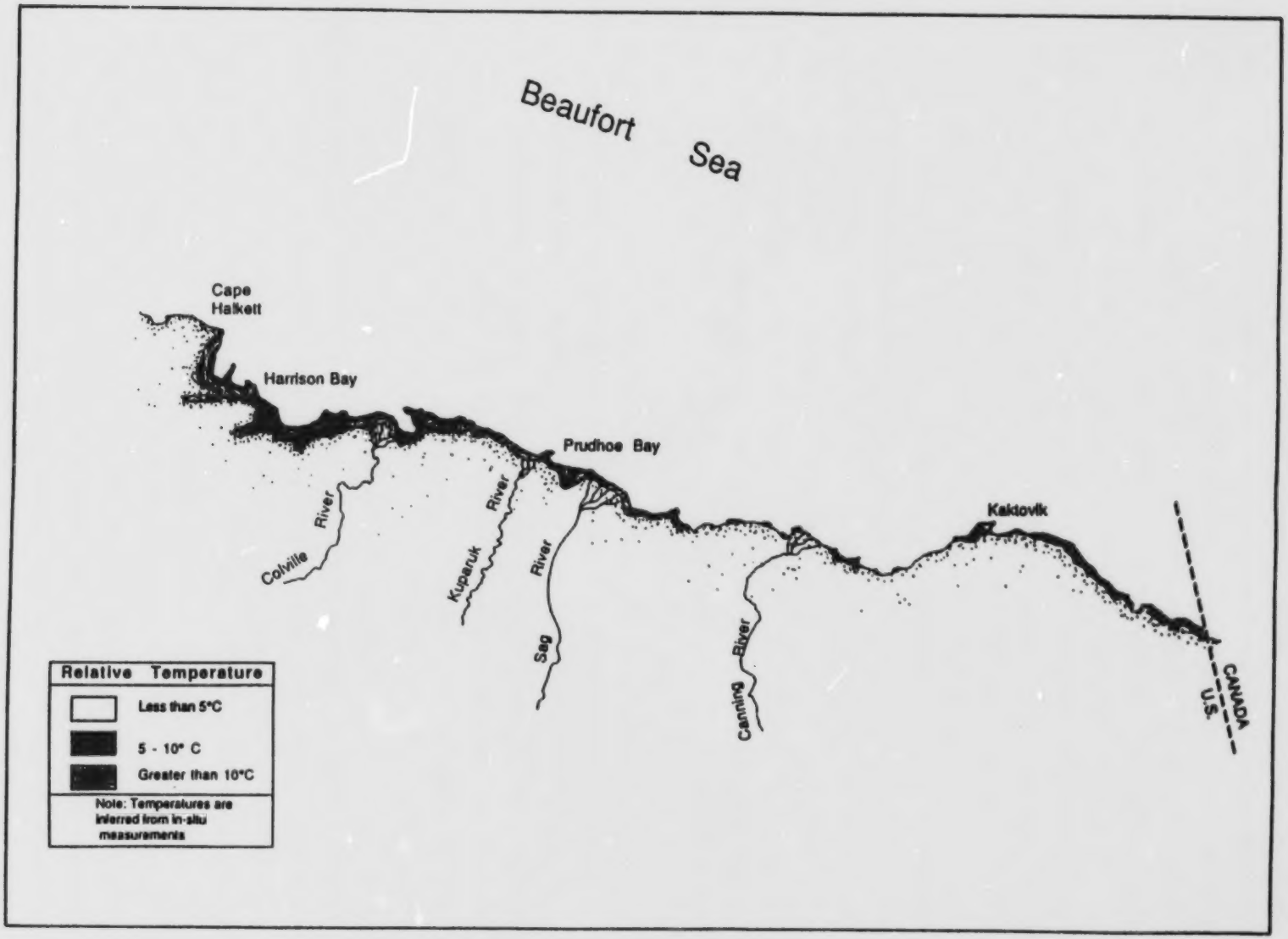


Figure 8. Generalized depiction of the extent of warm water habitat (shaded area) in the central Beaufort Sea. Based on relative sea surface temperature of the Beaufort Sea near coastal water interpreted from NOAA-9 polar orbiting satellite advanced very high resolution radiometer (AVHRR) 2 August 1985 (adapted from Gallaway et al. 1988).

relatively marine. In general, however, the six years of study near Prudhoe Bay have led to the consensus that water temperature is one of the principal factors controlling the distribution and movement of anadromous fish.

Salinity

The detection of salinity tolerances in anadromous fish is confounded by the strong association between salinity and temperature; water masses tend to be either warm and brackish or cold and saline. Consequently, the avoidance of cold temperatures might also include some degree of avoidance of high salinity conditions.

Despite the difficulty in separating responses to temperature and salinity, there is general agreement that Arctic anadromous fish tend to avoid high salinity conditions. This belief stems primarily from the fact that all of the species in question are not "true" anadromous fish, since they enter the coastal environment only briefly each year to take advantage of the abundant food resources (Craig 1988). This is in contrast to "true" anadromous species like salmon, which spend nearly their entire life in the open ocean before returning to fresh water to spawn. It is likely that temperature in conjunction with salinity are the two primary physical factors controlling the coastal movements and distribution patterns of Arctic anadromous fish.

Currents

The effect of currents on migration, movement and distribution is also confounded by the effects of temperature and salinity. The clearest example of the effect of currents found in the Prudhoe Bay studies, is for the eastward migration of small least cisco from the Colville River. During years dominated by east winds, few small least cisco arrive at the eastern end of the barrier island-lagoon system, near West Dock. Under east winds, the current flows from east to west in the lagoon. While the absence of small least cisco under these conditions is likely due in large part to an aversion to cold, saline

conditions, it may also reflect an unwillingness to move against prevailing currents. In contrast, substantial numbers of large least cisco reached West Dock and Prudhoe Bay regardless of prevailing wind patterns. Larger fish, being more powerful swimmers, have the physical capability to overcome westward flowing currents. Their presence in the study area could also reflect a greater tolerance for colder, more saline conditions. The complex association among temperature, salinity, and current makes it difficult to determine the exact role of the latter.

An instance where currents do play a role in movement is the yearly recruitment of age 0^+ (young-of-the-year) Arctic cisco from the Mackenzie River, Canada. Fechhelm and Fissel (1988) recently provided evidence that the success of yearly recruitment of Mackenzie Arctic cisco into Alaskan waters is linked to wind-driven coastal currents. The higher the proportion of easterly winds (westerly flowing currents) during summer, the higher the recruitment rate. They point out that changes in the Colville commercial fishery and native subsistence harvest of Arctic cisco that might be construed as an indication of environmental impact caused by industry, may in fact be caused by natural phenomena.

The 1985 and 1986 Prudhoe Bay studies also suggest that current is an important controlling mechanism. In 1985, large numbers of age 0^+ Arctic cisco passed through the study area from east to west (Cannon et al. 1987a). Patterns in fyke net catch indicated these fish moved in conjunction with longshore currents passing eastward through Foggy Island Bay, past the Endicott and West Dock causeways, and continuing westward, although some individuals did remain and take up residence in the Sagavanirktok River. In 1986, young-of-the-year Arctic cisco appeared to move into the Prudhoe Bay area from the west, the exact opposite of the pattern expected for fish migrating from Canada to Alaska (Glass et al. 1986). The interpretation of this event is that fish were carried offshore past Prudhoe Bay in conjunction with longshore currents driven by easterly winds, and when a shift to

westerly winds occurred, offshore surface waters were transported onshore carrying the newly recruited fish with them.

EFFECTS OF CAUSEWAYS ON FISH AND THEIR HABITATS

Extensive seasonal monitoring studies of fish movement and distribution patterns, in relation to causeways, have been conducted in the Prudhoe Bay/Sagavanirktok Delta area from 1981 to the present. These studies have shown that the four key anadromous species consistently prefer or are at least more abundant in warm brackish water habitats than the cold marine water areas. As expected the degree of tolerance to low temperatures and high salinities is variable among species and size classes.

As previously described, the water masses and corresponding current speeds and directions within the region are controlled by prevailing winds. The following sections summarize the open-water movements and distribution patterns of the four key anadromous species in relation to water mass movements, in the vicinity of the two major causeways, West Dock and Endicott.

Least Cisco

General Movement Patterns

Most least cisco found in the Prudhoe Bay/Sagavanirktok Delta area originate from spawning and overwintering grounds in the Colville River. Fish enter coastal waters shortly after breakup, and a portion of the population disperses eastward along the coast to feed. They appear to move primarily within the warmer and less saline waters of the barrier island-lagoon system that extends from the Colville River to Prudhoe Bay (Moulton et al. 1986; Cannon et al. 1987a; Fechhelm et al. 1988). Small least cisco (<250 mm FL) tend to move along the mainland shore of the lagoon complex where waters are warmest (Moulton et al. 1986; Fechhelm et al. 1988). The larger fish (>250 mm FL), being more temperature and

salinity tolerant, use the entire lagoon system, frequently moving along the barrier islands themselves.

Least cisco first appear at the eastern end of the barrier island-lagoon system in late June to early July. Progressively smaller-sized cohorts arrive at progressively later dates (Moulton et al. 1986; Fechhelm et al. 1988), with small least cisco generally not being represented in fyke net catches at West Dock until after mid-July. This size-dependent arrival date might only reflect size-dependent swimming speeds.

All size classes tend to arrive in the Prudhoe Bay/West Dock area during or shortly after periods of predominantly west winds (Critchlow 1983; Moulton et al. 1986; Cannon et al. 1987a; Fechhelm et al. 1988). Westerly winds cause water to flow to the east within the barrier island-lagoons and the eastward deflection of the Colville and Kuparuk river water results in warmer and less saline conditions at the eastern end of the barrier island complex. Warmer water temperatures, lower salinities and easterly flowing currents all appear to facilitate the eastward dispersal of least cisco from the Colville River. This association is most pronounced for smaller fish (Fechhelm et al. 1988).

In years dominated by easterly winds, most small least cisco do not reach the eastern end of the lagoon system (Woodward-Clyde Consultants 1983; Biosonics 1984; Cannon et al. 1987a). The combination of strong marine intrusions on the west side of West Dock, and the westward deflection of discharge waters from the Kuparuk and Colville River promote cold and saline conditions at the eastern end of the barrier island-lagoon system. These conditions, coupled with westerly currents, tend to inhibit the migration of least cisco eastward from the Colville River.

Once past West Dock, least cisco appear to use Prudhoe Bay and the Sagavanirktok River delta as feeding habitat. Use of the Sagavanirktok Delta increases during marine intrusions into Prudhoe Bay. During such events, least cisco numbers drop sharply in Prudhoe Bay and their

abundance increases in the vicinity of the Sagavanirktok Delta, suggesting that fish retreat in the face of the marine front. Once the marine water dissipates because of mixing with nearshore brackish water and changes in the wind conditions, fish re-occupy Prudhoe Bay (Critchlow 1983; Woodward-Clyde Consultants 1983; Griffiths et al. 1983; Moulton et al. 1986; Fechhelm et al. 1988).

The period of residency in the Prudhoe Bay area is variable and depends upon their arrival date and overall hydrographic conditions for the season. In 1984, cohorts of small (<250 mm FL) least cisco did not reach the West Dock causeway area until about 20 July. These same size groups reached Prudhoe Bay during the second week in July 1981 (Griffiths and Gallaway 1982; Moulton et al. 1986).

Emigration from Prudhoe Bay and the return to the Colville River generally takes place over a period of 2-3 weeks beginning in early August. Few least cisco of any size class are collected in the Prudhoe Bay/Sagavanirktok River delta area after 1 September (Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987a; Glass et al. 1986).

Effects of West Dock Causeway

The eastward movement and distribution of least cisco beyond West Dock depends on prevailing wind patterns. During westerly winds, warm, low-salinity water flowing east through the lagoon complex is deflected seaward by the West Dock causeway. Offshore currents then deflect this plume eastward from the causeway tip and into Prudhoe Bay (Savoie and Wilson 1986). Under these conditions, all size classes of least cisco are able to move east around the causeway (Fig. 9A).

During easterly winds, intense marine upwellings occur on the west side of the causeway and cause the eastern end of the barrier island-lagoon complex to become cold and saline (see Fig. 4) These marine intrusions are exacerbated by the presence of the West Dock causeway (see Physical Processes Section). Under these conditions, all sizes of least cisco

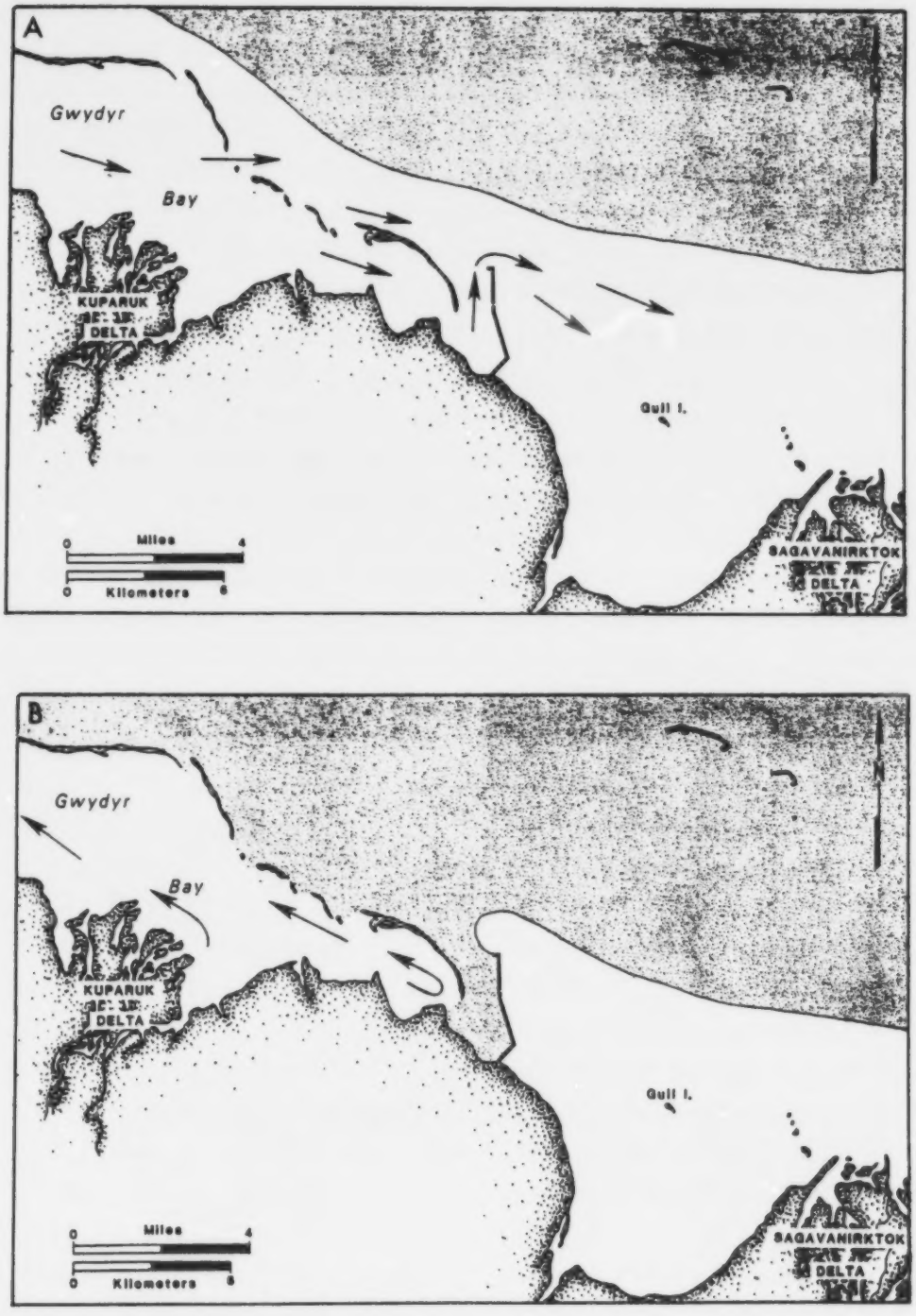


Figure 9. Conceptualized map of least cisco migration patterns (A) under northwesterly winds and (B) under northeasterly winds. Arrows represent fish and shaded areas represent cold, saline wate (adapted from Fechhelm et al. 1988).

within the barrier island-lagoon system are pushed westward by the marine water mass (Griffiths and Gallaway 1982; Critchlow 1983; Moulton et al. 1986; Fechhelm et al. 1988). Thus, during periods of easterly winds, marine conditions west of the West Dock causeway serve to block eastward dispersal (Fig. 9B).

West Dock causeway can also block the eastward movement by directing least cisco seaward toward colder, more saline offshore waters. A major reversal in the longshore migration of large least cisco was detected in 1984 when eastward-moving fish apparently encountered a strong marine water interface at the tip of West Dock causeway (Moulton et al. 1986; Fechhelm et al. 1988). The fish apparently moved back towards the Colville River, and were not recorded in the West Dock/Prudhoe Bay area for the remainder of the season. This implies that a complete blockage of their feeding dispersal into Prudhoe Bay occurred in 1984.

West Dock may also temporarily delay the eastward dispersal of least cisco. In 1983, large numbers of small least cisco moved into the eastern end of the barrier island-lagoon complex during a period of westerly winds. Although these winds continued for the next 48 h, few fish moved east of West Dock. After 48 hours, the winds shifted to easterlies and water conditions became cold and marine immediately west of the causeway, and catches dropped precipitously as fish retreated westward out of the area (Critchlow 1983; Griffiths et al. 1983; Fechhelm et al. 1988). Thus, despite favourable conditions for a period of 48 h, fish did not move eastward around West Dock. Since fish may have a limited number of opportunities to move east around West Dock, such temporary delays decrease the probability of eastward dispersal.

Gallaway et al. (1988) estimated that the deterioration of the nearshore warm-water habitat, due to causeway-induced marine intrusions, would directly affect about 8% of the Colville/Sagavanirktok River Habitat Unit (see Fig. 8). In addition, these disruptions could potentially prevent least cisco from accessing approximately 35% of their potential summer habitat (i.e., the coastal area lying east of

West Dock). However, such conditions occur only intermittently, and there are even some years (with predominantly strong east winds) when such a discontinuity is irrelevant since least cisco do not reach the causeway area.

Emigration of least cisco from Prudhoe Bay is often associated with periods of easterly winds, and it is believed that fish moving westward pass around the tip of West Dock causeway in conjunction with the warm, brackish water plume emanating from the Sagavanirktok River delta (Critchlow 1983; Moulton et al. 1986). Fish moving westward around the causeway may continue along the marine side of the barrier islands (Moulton et al. 1986) or may pass into the lagoon systems (Cannon et al. 1987a). Analysis of tag returns in the Colville River commercial fishery indicates that the presence of West Dock has no effect on return rates of large least cisco (Fechhelm et al. 1988; Cannon and Hachmeister 1987). Similar analyses cannot be performed with small least cisco.

Effects of Endicott Causeway

The effects of the Endicott causeway on the dispersal of small least cisco are uncertain. Easterly winds have prevailed in both years since the construction of the causeway. Under these conditions few small least cisco have dispersed eastward from the Colville River into the area and data are inadequate to make an assessment (Cannon et al. 1987a; Glass et al. 1986). Fyke net catches indicate that larger least cisco move freely around the Endicott causeway, with large numbers of fish being present as far east as Foggy Island Bay (Cannon et al. 1987a; Glass et al. 1986). Although marine intrusions do occur along the western portion of the Endicott causeway, they are less intense than those that occur in the vicinity of West Dock causeway (Savoie and Wilson 1986; Short et al. 1987). However, they are apparently not severe enough to block longshore movement of large individuals. There are not enough data on small individuals to reach a conclusion.

Cumulative Effects Of West Dock and Endicott Causeways

Because the Endicott causeway apparently elicits no affect on the longshore migration of large least cisco the cumulative effect of both causeways on these individuals may be no greater than that linked to West Dock alone. In the case of small least cisco there are insufficient data at present to determine the cumulative effect of the two causeways.

Arctic Cisco

The movement and migration patterns for Arctic cisco are more difficult to document and describe than those for least cisco mainly because of their more complicated life history which appears to involve:

1. regional migrations to and from spawning areas that may involve long distances of several 100 km;
2. the occupancy of feeding and overwintering areas as juveniles and subadults remote from their natal streams; and
3. their relative tolerance to cold marine waters which tends to blur their reactions to changes in oceanographic conditions.

In order to clarify the movement patterns of Arctic cisco, the Colville and Sagavanirktok overwintering stocks will be discussed separately.

Colville River Stock/Effects of West Dock Causeway

Large Arctic cisco (>250 mm FL) disperse from their overwintering areas in the Colville River estuary and move along the coast in a pattern similar to that described for least cisco. A portion of the Colville River population moves east through, and along the outside of, the barrier island-lagoon system. As with least cisco, Arctic cisco arrive in the vicinity of West Dock, at the eastern end of the lagoon

complex, at progressively later dates, depending on size (Moulton et al. 1986; Fechhelm et al. 1988).

Mark-recapture and catch data from 1981-1986 indicated that few large Arctic cisco from the Colville River remain in the Prudhoe Bay/Sagavanirktok Delta area for the open-water season. This low residency rate may reflect the return migration of the maturing fish to the spawning areas in the Mackenzie River (Fechhelm et al. 1988). It may also reflect the fact that large Arctic cisco range along much of the Beaufort Sea coast during the open-water period (Kendel at al. 1975; Griffiths et al. 1975, 1977; Schmidt et al. 1988; Moulton et al. 1986). Fish moving east of West Dock may continue dispersing to the east, and reduced residency time in the Prudhoe Bay/Sagavanirktok Delta area lowers the probability of recapture in fyke nets.

These factors combine to obscure the effects of West Dock on the dispersal of large Colville River Arctic cisco in relation to the nearscale hydrology around the causeway. The low abundances east of West Dock could either be interpreted as evidence that fish were prevented from moving around the causeway, or that the numbers were low due to the combination of events described above. However, the fact that large Arctic cisco are able to move around West Dock was evident from tag recoveries in the Colville River commercial fishery, where there were no significant differences in the return rate from large individuals tagged either east or west of West Dock causeway (Critchlow 1983; Moulton et al. 1986).

The effect of the West Dock causeway on the movement of small (<250 mm FL) Colville River Arctic cisco is also unclear. This is because, unlike least cisco and large Arctic cisco, small Arctic cisco overwinter in both the Colville and Sagavanirktok deltas. Small Sagavanirktok Arctic cisco are present throughout the Prudhoe Bay/Sagavanirktok Delta area from breakup to freeze-up, and their presence masks the arrival, subsequent movements, and departure of similarly-sized fish from the Colville River.

Increases in catch-per-unit-effort (CPUE) of small Arctic cisco on the west side of West Dock often coincides with the arrival of small least cisco from the Colville River, and it is likely that these surges in CPUE represent the arrival of small Colville River Arctic cisco (Moulton et al. 1986). Because studies have shown that both small Arctic cisco and small least cisco generally exhibit the same preference for warm, brackish water (Critchlow 1983; Griffiths et al. 1983; Moulton et al. 1986; Cannon et al. 1987a; Glass et al. 1986), it is likely that movements of small Colville River Arctic cisco would be similar to small least cisco. Wind-induced cold, marine upwellings on the west side of West Dock could either delay further eastward dispersal or cause small Arctic cisco to retreat westward toward the Colville River (Moulton et al. 1986; Fechhelm et al. 1988). In addition, westward migration of small Arctic cisco around West Dock to overwintering areas in the Colville Delta could also be affected. During periods of easterly winds, westward movement would be enhanced by Sagavanirktok plume water that is shunted across the tip of the causeway (see Causeway and Local Physical Processes), while westerly winds at this time could delay or block westward movement (Gilbertson et al. 1987).

Colville River Stock/Effects of Endicott Causeway

The effects of the Endicott Causeway on large Arctic cisco are thought to be minimal, since the east to west migration route was shifted only slightly seaward by the causeway (Gilbertson et al. 1987). The low abundance of large Arctic cisco in the vicinity of the Endicott causeway during the open-water season was likely due to the same combination of factors described above for West Dock. Tag recoveries in the Colville River commercial fishery suggested that return westward migration was not affected by the presence of the Endicott causeway.

Because of the methods used in the studies to date (i.e., only large individuals were tagged) small Arctic cisco from the Colville River are essentially indistinguishable from the more numerically dominant Sagavanirktok River stock, and this precludes an assessment of the impacts of the Endicott causeway on the Colville River stock.

Sagavanirktok River Stock/Effects of West Dock Causeway

It should be noted that prior to 1986 large Arctic cisco (>250 mm FL) in the region were probably from the Colville River, since the vast majority of Sagavanirktok Arctic cisco were small fish (<250 mm FL) recruited from the 1979 year class (Moulton et al. 1986; Fechhelm et al. 1988). Thus, the Sagavanirktok stock of Arctic cisco has been dominated by the 1979 year-class from 1981 to the present. This cohort has increased in mean modal length from approximately 100 mm FL in 1981 (Griffiths and Gallaway 1982) to 300 mm FL in 1986 (Glass et al. 1986). Consequently, only small individuals (<250 mm FL) were represented in this stock until the summer of 1986. Because Arctic cisco appear to become more tolerant of colder temperatures and higher salinities with age, changes in the distribution and movements of the 1979 year-class over the six years of study may relate to physiological changes within the species.

The movement and distribution of the 1979 year-class appeared to be strongly associated with the warm, low salinity plume of the Sagavanirktok River. With few exceptions, catches tended to be highest in the western Sagavanirktok Delta and Prudhoe Bay (Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987a; Glass et al. 1986). Dispersal west of West Dock appeared to be a function of daily wind patterns and the subsequent eastward or westward deflection of the Sagavanirktok River plume.

One of the clearest examples of plume-directed movement occurred in 1981, when the largest seasonal peak in CPUE for small Arctic cisco occurred in catches from fyke nets operating in the vicinity of West Dock on 4-5 August. Prior to 3 August, winds had been predominantly from the west. A shift from westerly to mixed/weak-northeasterly winds on 3 August deflected the Sagavanirktok plume westward, and water temperature subsequently increased in the vicinity of the causeway (Fig. 10). As described previously, east winds generally cause conditions to

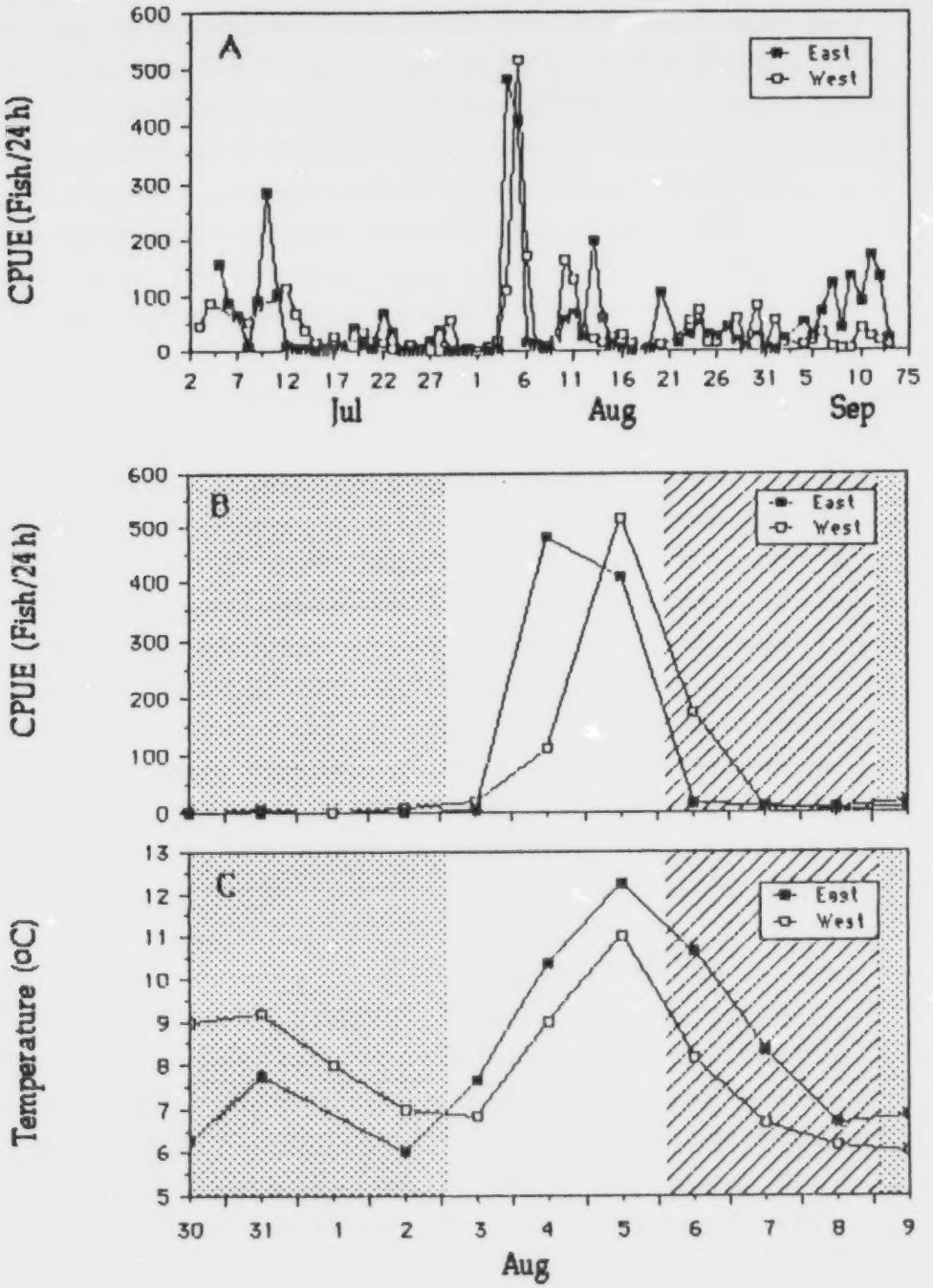


Figure 10. Catch-per-unit-effort (fish/24 h) of small Arctic cisco east and west of West Dock (A) for the 1981 open-water season, (B) for the period 30 July to 9 August 1981, and (C) water temperature for the period 30 July to 9 August 1981. Stippled area represents west winds, hatching lines represent strong northerly winds.

become colder and more saline immediately west of West Dock; whereas, weak north/northeasterlies can cause the Sagavanirktok River plume to dip down into the barrier island lagoons and along the west face of the causeway (Savoie and Wilson 1986). This appeared to be the case in 1981, and catches of small Arctic cisco peaked at nets east of West Dock on 4 August and at nets west of the causeway on 5 August. (Sequential surges in CPUE are often used to assess the direction of movement.) Strong northerly winds began on 6 August, blowing offshore water onshore which resulted in decreased water temperatures and reduced catches of Arctic cisco on both sides of the causeway.

In years characterized by equal proportions of easterly and westerly winds (e.g. 1982), few Sagavanirktok Arctic cisco are taken either west of West Dock causeway or in western Prudhoe Bay (Critchlow 1983; Griffiths et al. 1983; Moulton et al. 1986). Under these conditions, the causeway was probably not a factor in determining distribution, since oceanographic conditions change with the wind and long-term adverse conditions would be unlikely. In years when easterly winds dominated (e.g. 1985 and 1986), the Sagavanirktok plume was moved westward and catches west of West Dock causeway at times exceeded those in Prudhoe Bay and the western Sagavanirktok Delta (Cannon et al. 1987a; Glass et al. 1986).

The extent to which West Dock causeway blocks or delays westward dispersal during periods of prevailing easterly winds is uncertain. As discussed in the Physical Processes section, marine intrusions are more severe immediately west of West Dock during easterly winds than they are immediately east of the structure during westerly winds. In addition, fish moving westward around the causeway during periods of east winds have the advantage of using the surface plume from the Sagavanirktok River. West Dock thus presents a greater barrier for fish moving eastward than for fish moving westward and consequently may offer less of a barrier to Arctic cisco dispersing westward from the Sagavanirktok River delta.

If easterly winds persist throughout the later part of the summer, conditions around the West Dock causeway might inhibit easterly movement of Arctic cisco back to their overwintering grounds in the Sagavanirktok River, since these fish may be required to migrate through cold, saline conditions that develop at the eastern end of the barrier island-lagoon complex, the area most severely affected by marine intrusions.

Sagavanirktok River Stock/Effects of Endicott

The 1985 and 1986 surveys in the vicinity of the Endicott causeway provide evidence of dispersal of large Arctic cisco east of the Sagavanirktok Delta. CPUE in Foggy Island Bay for the 1979 year-class often equalled CPUE observed in other parts of the study area during both years (Cannon et al. 1987a; Glass et al. 1986). Extended dispersal for older larger fish probably reflects an increased tolerance to colder, more saline conditions. Effects of the Endicott causeway on local movements of small Arctic cisco are unknown because of their scarcity in the study area. It should be noted that large numbers of small Arctic cisco, presumably recruited from Canada, arrived in the study area in late August and early September. These fish were far too small to mark (<100 mm FL) so that only their overall distribution patterns could be determined (see below).

There are, to date, no indications that the Endicott causeway has prevented the recruitment of small Arctic cisco across the Sagavanirktok Delta to western regions (Cannon et al. 1987a; Glass et al. 1986). In particular, the 1986 survey showed that small Arctic cisco, presumably recruited from Canada in 1985, were more abundant in Prudhoe Bay and the western side of the Sagavanirktok Delta, than on the eastern side or in Foggy Island Bay (Glass et al. 1986).

Cumulative Effects of West Dock and Endicott Causeways

Cumulative effects of the two causeways on Arctic cisco movements are difficult to assess because the effects of a single causeway are not always clear. However, long-distance regional movements are still

occurring since small age 0^+ Arctic cisco, apparently migrating from the Mackenzie River, reached the Colville Delta in the fall of 1985 (Fawcett et al. 1986). Similarly, large Arctic cisco tagged west of the two causeways have been recaptured to the east of the structures in the Colville commercial fishery. These results suggest that the two causeways do not form a total block to the movements of large or small Arctic cisco. However, smaller local effects, such as the blockage of a percentage of the migrating fish are not detectable, mainly due to the lack of comparable data from pre-causeway conditions.

Arctic Charr

General Movement Patterns

Most of the Arctic charr collected in the Prudhoe Bay/Sagavanirktok Delta area are believed to originate from the Sagavanirktok River. In mid-June, when the first fyke net sets of the season are placed in the open-water leads near the mouth of the Sagavanirktok, they catch all size-classes of Arctic charr, suggesting that fish migrate downstream and enter coastal waters at breakup (Cannon et al. 1987a; Glass et al. 1986). Arctic charr abundance tends to be high until about mid-July when catches decline. The catch rates increase again near the end of August, when large numbers of juvenile charr returning to their overwintering areas are collected near the entrance to the west channel of the Sagavanirktok Delta. Relatively few Arctic charr are collected in the region after early-September (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton et al. 1986; Cannon et al. 1987a; Glass et al. 1986).

The mid-season decline in Arctic charr abundance suggests a dispersal out of the study area. Although the reasons for this dispersal are not known it could result from an along shore movement to feeding areas outside the region or charr may move further offshore to feed on high concentrations of epifaunal prey that concentrate along the interface between the offshore, marine-water mass and the nearshore,

brackish-water mass (L. Moulton, pers. comm.). This species is also the most piscivorous of the anadromous fish species (Moulton et al. 1986; Cannon et al. 1987b), and a move offshore would bring them in closer proximity to large concentrations of Arctic cod (Boreogadus saida).

The apparent ability of charr to move freely along the coast probably reflects both their euryhaline nature and their swimming ability. Mark-recapture studies have shown that large charr may travel long distances at rates of up to 20 km per day (Moulton et al. 1986). One fish marked in Foggy Island Bay was recovered about 130 km to the east three weeks later at Kaktovik (Cannon et al. 1987a). A fish from Simpson Lagoon was recovered 140 km to the east in the Canning River (Craig and Haldorson 1981). Furniss (1975) reported that charr tagged in Prudhoe Bay have been recovered as far as 300 km away near Barrow, Alaska.

Small charr also move considerable distances; fish marked near West Dock causeway in 1982 (Critchlow 1983) and in Prudhoe Bay during 1983 (Woodward-Clyde Consultants 1983) were recovered approximately 55 km to the west near Oliktok Point (see Fig. 1) during the same year. In general, Arctic charr of all size classes appear to move freely along the coast during most of the open-water season. Of the four anadromous species, Arctic charr appear least affected by short-term shifts in water temperature and salinity.

Effects of West Dock Causeway

Studies to date indicate that the effects of West Dock on the distribution and movement of Arctic charr are minimal (Griffiths and Gallaway 1982; Critchlow 1983; Moulton et al. 1986; Cannon et al. 1987a). Charr are both euryhaline and eurythermal, and it is thought that they have a much wider dispersal corridor than the other anadromous species. This suggests that they are not impeded by local temperature and salinity regimes around the causeway. In addition, since individual fish spend little time in the Prudhoe Bay/Sagavanirktok Delta

area they are not in the proximity of West Dock for most of the open-water season.

Effects of Endicott Causeway

Studies indicate that the effects of the Endicott Causeway on the dispersal of small and large Arctic charr are minimal (Griffiths and Gallaway 1982; Critchlow 1983; Moulton et al. 1986; Cannon et al. 1987a). In fact, effects are probably less than those of West Dock, since the marine conditions that develop around the Endicott structure are not as pronounced.

Cumulative Effects Of West Dock and Endicott Causeways

There is no evidence of synergistic effects of West Dock and the Endicott Causeway on the open-water distribution patterns of small or large Arctic charr.

Broad Whitefish

General Movement Patterns

Broad whitefish are the most stenohaline of the anadromous species. They remain in brackish water in close proximity to freshwater drainages during the open-water season. This is particularly true for small (<250 mm FL) individuals. Typically, the average seasonal CPUE is highest in the immediate vicinity of the Sagavanirktok Delta and along the southern shore of Prudhoe Bay (Griffiths et al. 1983; Woodward-Clyde Consultants 1983; Moulton et al. 1986; Cannon et al. 1987a). Conversely, CPUE in northwestern Prudhoe Bay and west of West Dock causeway is consistently low (Griffiths and Gallaway 1982; Critchlow 1983; Biosonics 1984; Moulton et al. 1986).

The seasonal distribution pattern for large (>250 mm FL) broad whitefish is essentially the same as for smaller individuals with two notable exceptions. First, substantial numbers of large fish have been

collected near the Kuparuk Delta. These probably represent fish that migrated eastward during the early part of the season from the Colville River. There is no evidence that broad whitefish overwinter and/or spawn in the Kuparuk River. Catch in the Kuparuk Delta area drops to negligible levels by early August (Moulton et al. 1986; Cannon et al. 1987a). Large fish apparently feed in the vicinity until mid-summer, then leave the area. Small broad whitefish from the Colville River do not occur in any appreciable numbers in the Kuparuk Delta area.

The second distinction between the distributions of small and large broad whitefish is that the latter were also taken in large numbers in Foggy Island Bay during 1985 and 1986. These fish probably represent individuals that overwinter in the Sagavanirktok River.

The presence of Colville River broad whitefish in the Kuparuk delta indicates that large fish do migrate along the coast. However, such a dispersal pattern may be a reflection of the unique conditions along the coast between the Colville River and West Dock. In this area a chain of barrier islands protects the nearshore lagoon system from the influence of cold, marine, offshore water. In addition, the area is directly influenced by the warm-water discharges of the Colville and Kuparuk rivers. The presence of this warm, low salinity pathway may facilitate coastal migration. Moderately high catches of large broad whitefish have been recorded on both sides of the West Dock causeway; these sporadic increases in CPUE occur during periods when warm, low salinity water is flowing toward the structure. Coastal migrations and dispersals are more restricted along the exposed segments of the coast.

The brackish water preference of broad whitefish is also apparent from correlation analyses that have repeatedly shown positive associations between CPUE and temperature and negative associations between CPUE and salinity (Griffiths and Gallaway 1982; Critchlow 1983; Griffiths et al. 1983). Freshwater influence is also apparent from dietary studies in which the major food item is chironomid larvae, an insect that is restricted to fresh water and affiliated estuaries (Moulton et al. 1986; Cannon et al. 1987b).

Effects of West Dock Causeway

West Dock does not appear to act as a major barrier to longshore migrations of broad whitefish because it is not located on a major migratory pathway. Small Sagavanirktok broad whitefish do not disperse far enough to the west to come under the influence of the causeway, and while large individuals do occasionally move into the causeway area, from both the Colville and Sagavanirktok rivers, they do so only sporadically throughout the season (Griffiths and Gallaway 1982; Critchlow 1983; Biosonics 1984; Moulton et al. 1986). Of the few small broad whitefish taken just east of West Dock causeway, most were collected during periods of easterly winds. This suggested that small broad whitefish distribution changes in conjunction with shifts of the Sagavanirktok River plume. Although plume deflection may bring small fish close to West Dock causeway, such conditions occur only occasionally during the summer. If the causeway was on a migratory route, the effects on broad whitefish would be similar to those described for least cisco (see above).

Effects of Endicott Causeway

There is no evidence that the movements of small or large broad whitefish across the Sagavanirktok Delta are seriously affected by the Endicott Causeway (Gilbertson et al. 1987). The small individuals tend to remain in close proximity to the shore throughout the open-water season, and while large broad whitefish range further along the coast their movements are not extensive. When cold marine water moves up on the outer side of the causeway, broad whitefish can and do move across the delta by making use of the two breaches located in the interisland to mainland portion of the causeway (Gilbertson et al. 1987).

Cumulative Effects Of West Dock and Endicott Causeways

There is no evidence of cumulative effects of West Dock and the Endicott Causeway on the movements of either small or large broad whitefish.

Effects on Fish Populations

The preceding sections have dealt with the direct effects of causeways on the movement, distribution, and habitat use by individuals of the four anadromous species. However, the ultimate question is whether these impacts have effects on the populations. Population effects can be manifested in several ways. A reduction in the amount of high quality feeding habitat could lead to reduced growth rates and poorer physical condition which can result in reduced reproductive success by the population and a decline of the stocks of fish. Migration blockages could result in fish having to overwinter in less than ideal habitat, causing increased mortality and a reduction in population levels.

Arctic Charr

Populations of Arctic charr from several rivers occur in the study area at various times during the open-water period. As discussed above, neither the West Dock nor the Endicott causeways appear to have had any appreciable effect on large or small Arctic charr. The factor limiting Arctic charr populations appears to be overwintering habitat (Craig 1988); this habitat occurs near perennial springs typically located in the tributaries of the charr rivers.

The growth rates of Arctic charr during their first summer in nearshore waters (i.e., 3 to 4 year olds) have not shown any differences among years or studies. In the Prudhoe Bay/Sagavanirktok Delta region, these fish showed a steady increase in length of approximately 1.2 mm/day in 1982 and 1.1 mm/day in 1984 (Griffiths et al. 1983; Moulton

et al. 1986). During 1983, similar growth rates were reported for small charr in Prudhoe Bay and in the vicinity of Oliktok Point, about 50 km west of West Dock (Moulton et al. 1985; Moulton and Fawcett 1984). These results suggest that the condition factor of small Arctic charr has not been altered by the presence of the causeways. Since large Arctic charr have a relatively short residence time in the vicinity of the causeways, effects on their growth rate would be expected to be minimal.

Broad Whitefish

Two populations of broad whitefish occur in the study region, one from the Sagavanirktok River and one from the Colville River. The results of the numerous studies suggest that the broad whitefish on the east side of West Dock are primarily from the Sagavanirktok stock, while those on the west side are Colville River fish. As discussed above, the distribution patterns for broad whitefish are such that few small individuals and only a small number of large fish come under the influence of the West Dock causeway. In addition, any potential effects of the Endicott causeway have been mitigated by the presence of the two breaches (Gilbertson et al. 1987).

Growth patterns, based on daily increases in length over the open-water period, are the only data available on the condition of small (1 to 3 year olds) broad whitefish. These data suggest that there are no consistent differences between the growth rates for small broad whitefish in the Sagavanirktok and Colville rivers or among years (Griffiths et al. 1983; Fawcett et al. 1986; Moulton et al. 1986). In the case of large broad whitefish the only comparable data are from 1977-78 for Simpson Lagoon and 1984 for Prudhoe Bay. The results showed that the 1984 Prudhoe Bay broad whitefish were heavier for a given length than the 1977-78 broad whitefish in Simpson Lagoon (Craig and Haldorson 1981; Moulton et al. 1986). Although data were insufficient to determine if this difference was statistically significant, they do suggest that Sagavanirktok broad whitefish are in at least as good condition as the Colville River fish.

At the present time, the data suggest that there have been no effects on either of the broad whitefish populations due to the West Dock or Endicott causeways.

Least Cisco

The least cisco that utilize West Dock and the Prudhoe Bay region originate from the Colville River. Based on mean catch per day, between 30 and 50% of the large fish (>250 mm) and only about 5% of the small least cisco from the Colville stock entered the West Dock region (Critchlow 1983; Dew 1983; Woodward-Clyde Consultants 1983; Biosonics 1984; Moulton and Fawcett 1984). The catch-per-unit-effort from the Colville River commercial fishery suggests that the population levels of the large fish have remained relatively stable over the past twenty years and, if changing, have been slowly increasing. These data suggest that, up to the present time, the causeways have had minimal effect on the population levels of large least cisco. No similar estimates are available for small least cisco; however, since only about 5% of this size group come under the influence of the causeways, effects on populations would be negligible.

Growth measurements, based on length at age relationships from otoliths, for least cisco collected in the Colville Delta, Simpson Lagoon and Prudhoe Bay indicate similar growth curves for the years 1975 through 1985 (Fawcett et al. 1986). Thus, the condition factor for least cisco does not appear to have been affected by the presence of the West Dock or Endicott causeways.

Arctic Cisco

All of the Arctic cisco that occur in the region originally migrated over from the spawning areas in the Mackenzie drainage according to Gallaway et al. (1983). However, immigration into Alaskan waters appears to be sporadic since most of the small Arctic cisco in the study area from 1981 to 1985 were fish that had been overwintering

in the Sagavanirktok Delta since 1980. The exceptions to this are the small numbers of Arctic cisco that apparently migrated from the Mackenzie area in 1982, 1983 and 1984.

Most of the large Arctic cisco in the study area overwinter in the Colville Delta and disperse along the coast after breakup. However, winter studies conducted during 1985-86 (Adams and Cannon 1987; Schmidt et al. 1988) found that some large Arctic cisco overwinter in the Sagavanirktok Delta, but that the number was small when compared to those that used the Colville Delta (Moulton et al. 1986).

The growth of Arctic cisco has been examined during several studies (Griffiths et al. 1983; Moulton et al. 1986; Cannon and Hachmeister 1987; Gilbertson et al. 1987; Whitmus et al. 1987). In 1985, Whitmus et al. (1987) found no detectable differences in the length at age of Arctic cisco collected across the Beaufort Sea coast from the Colville to the Mackenzie rivers. However, Moulton et al. (1986) found that the growth rate of small Arctic cisco, from the abundant 1979 year-class, was lower for individuals from the Prudhoe Bay/Sagavanirktok Delta region than those from the Colville River area (Fig. 11). They attributed the reduced rate in the Sagavanirktok Delta to the high density levels per unit area in the Sagavanirktok compared to the Colville Delta. In addition, they noted that breakup occurred earlier in the Colville than in the Sagavanirktok Delta area and thus fish from the Colville Delta would have access to the abundant food supply in the nearshore region for a longer period of time than Sagavanirktok fish. However, as can be seen from Figure 11, the difference in growth rates occurred sometime between 1980 and 1982 and although it was maintained it did not increase. Data from the 1982 year-class showed no differences in growth rates between Sagavanirktok and Colville Arctic cisco (Cannon and Hachmeister 1987).

The difference in growth rates between the two overwintering stocks for the 1979 year-class is not clearly understood but may be due one or a combination of the following:

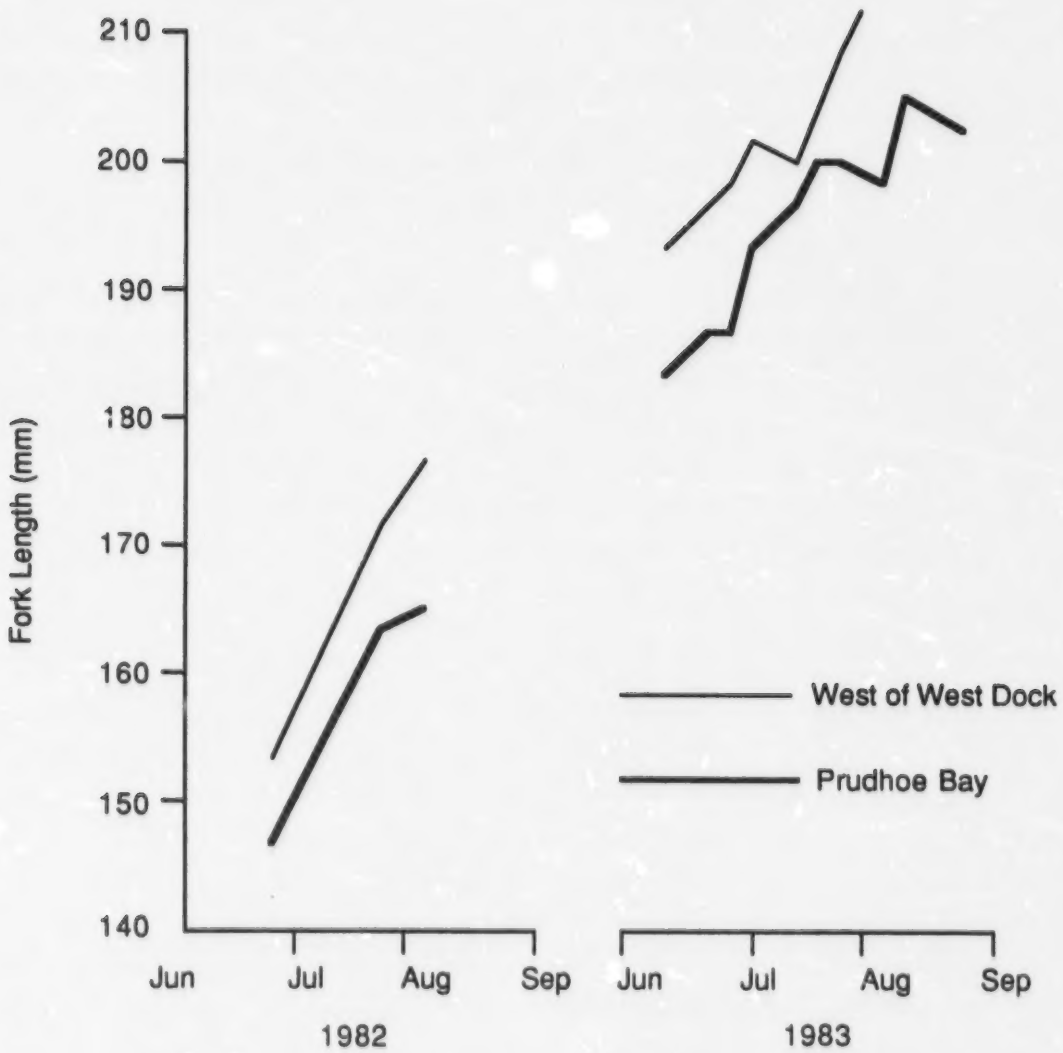


Figure 11. Comparison of growth rates of Arctic cisco collected in Prudhoe Bay in 1983 with those collected west of the West Dock causeway during 1983 and 1984.

1. Differences were due to density-dependent effects on growth. The small Arctic cisco in the Sagavanirktok Delta may have been overcrowded in the limited overwintering habitat for the first two years and were thus stressed and subsequently grew at a slower rate. After two years the population had decreased to levels where the habitat was no longer limiting and thereafter the growth rate parallelled that of the Colville Delta fish.

2. Differences were due to size-dependent swimming speed. Larger young-of-the-year Arctic cisco may have passed through the Prudhoe Bay area earlier than smaller young-of-the-year due to size related differences in swimming speed. The larger fish occupied the Colville Delta region, while the small fish were delayed to such an extent that they were forced to take up residence in the Sagavanirktok Delta. This would result in an initial size difference between the two groups and may also partially explain why this difference was maintained but did not increase.

Effects of the causeways on the population levels of Arctic cisco would depend on the percentage of the Mackenzie population that is recruited to the area. If the percentage is large, or if it represents a large portion of a single stock within the Mackenzie drainage, then there could be some causeway-induced impacts.

Young-of-the-year (age 0^+) Arctic cisco are transported down the Mackenzie River and into the Beaufort Sea. They then disperse to the east and the west during the open-water season and a portion of them take up residence in the Sagavanirktok and Colville rivers. Recruitment into Alaskan waters appears to be strongly influenced by nearshore coastal currents which are in turn determined by seasonal wind patterns. The strongest recruitment occurs in years dominated by easterly winds, i.e., westerly currents (Fechhelm and Fissel 1988). Of major concern is whether the presence of West Dock and the Endicott causeways impede or block natural dispersal patterns of newly arrived Arctic cisco. It is thought that because the Colville River provides more suitable overwintering habitat than the Sagavanirktok River (Schmidt et al.

1988), any blockage or hindrance of movement into this area would jeopardize the recruited population by reducing their chances of surviving the long winters. This concern takes on added relevance because it is not known what portion of young-of-the-year from the Mackenzie River is recruited to Alaska. If the proportion is large then impacts to migrants in Alaska may have far-reaching population level effects.

It is known that there are several widely separated spawning areas for Arctic cisco in the major tributaries of the Mackenzie River drainage. Each of these may represent a distinct stock; thus, it is possible that the dispersal of Arctic cisco into Alaska is stock specific. If this is the case, then causeway-induced impacts could have a large effect on a specific stock of Arctic cisco.

As discussed in the Movements section, seasonal catches in both the Prudhoe Bay and Colville River areas suggest that newly recruited Arctic cisco are not blocked from moving west of Prudhoe Bay (Fawcett et al. 1986; Cannon et al. 1987a; Glass et al. 1986). However, a recent analysis of the age structure of Arctic cisco taken in the 1987 Colville River fishery showed that the catch was dominated by 7^+ and 8^+ year-old fish, and there was a marked absence of 5^+ and 6^+ year-old fish (L. Moulton, pers. comm.). Arctic cisco first become large enough to be caught in the commercial fishery at age 5^+. It has been suggested that the absence of the 5^+ and 6^+ year-old fish may indicate that the recruitment of 0^+ Arctic cisco to the Colville River may have been blocked in 1981 and 1982 just after the Waterflood extension of West Dock had been completed. However, Fechhelm and Fissel (1988) have shown that recruitment strength is variable and is related to wind direction. This variation in recruitment strength is reflected five years later in commercial fishery catches (Fig. 12). Thus, the lack of age 5^+ and 6^+ fish in the 1987 fishery may represent poor recruitment to the Colville River in 1981 and 1982.

Evidence of poor recruitment to the Sagavanirktok River in 1981 and 1982 can be seen from the early season Arctic cisco length frequency data

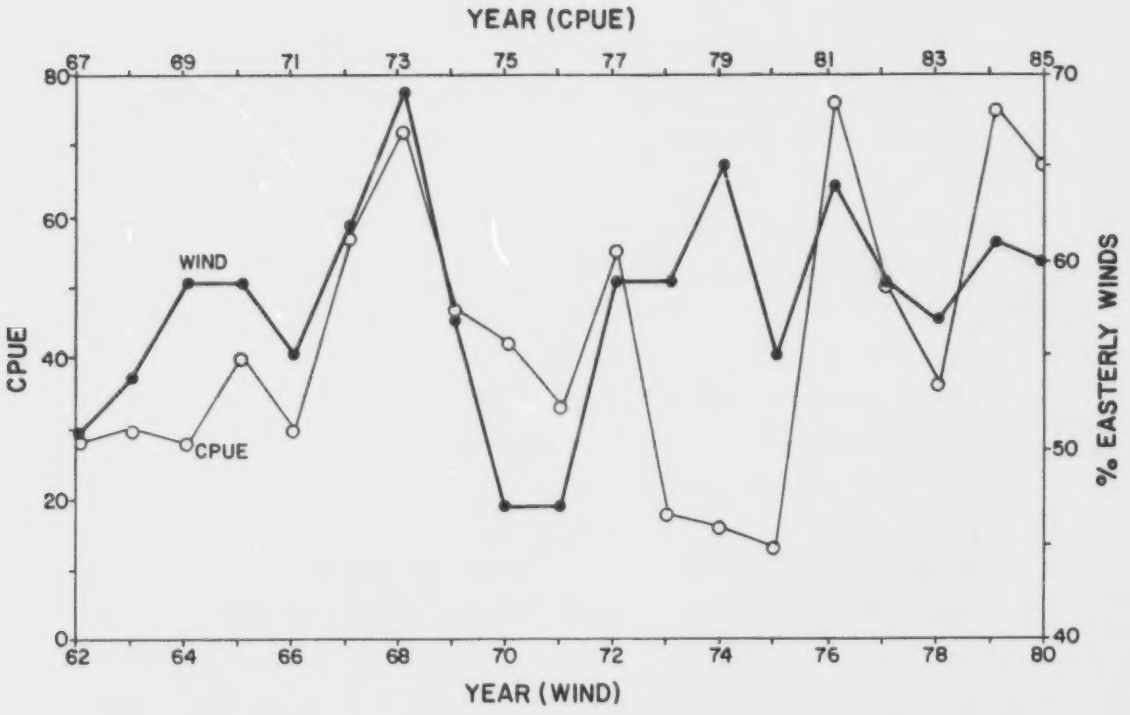


Figure 12. Catch-per-unit-effort (CPUE) of Arctic cisco at the Colville River commercial fishery by year and the percentage of easterly wind during the summer of their recruitment (adapted from Fechhelm and Fissel 1988).

collected in 1984. The two dominant size-cohorts in the Prudhoe Bay region were about 90-100 mm and 210-230 mm at the beginning of the season (Moulton et al. 1986; Fig. 13). The larger size fish have been in evidence in catches in the Prudhoe Bay studies since they began in 1981 and represent the 1979 year class. The smaller fish represent Arctic cisco that were recruited in 1983. There are no major modes in between, suggesting that 1981 and 1982 were years of poor recruitment. During the 1987 Colville fishery the missing cohorts would have been age 5^+ and 6^+; the two cohorts that in fact are not represented in the 1987 commercial fishery catch. The fact that 5^+ and 6^+ fish were absent from both sides of West Dock suggests that the causeway was not responsible for their absence. Rather, these classes were probably not recruited in great numbers into Alaskan waters in the first place (L. Moulton, pers. comm.).

An unusual aspect about the 1987 fishery was the presence of 7^+ and 8^+ year-old Arctic cisco. As discussed previously, Arctic cisco of this age have typically disappeared from the Colville River fishery, presumably because they have returned to the Mackenzie drainage to spawn.

Breach Effectiveness

The effectiveness of causeway breaches is a function of their location, size, and design. Over the six years of environmental studies conducted in the Prudhoe Bay area, there is no evidence that the breach in West Dock causeway benefits the longshore movement of anadromous fish. The West Dock breach is narrow (15 m wide), is located midway along the causeway's 3.9 km length, and regularly silts in. The numerous fisheries studies conducted in the region show that anadromous fish tend to move along the mainland shore of the barrier island-lagoon early in the season before entering Prudhoe Bay; consequently, a breach at the base of West Dock might more likely be used by fish.

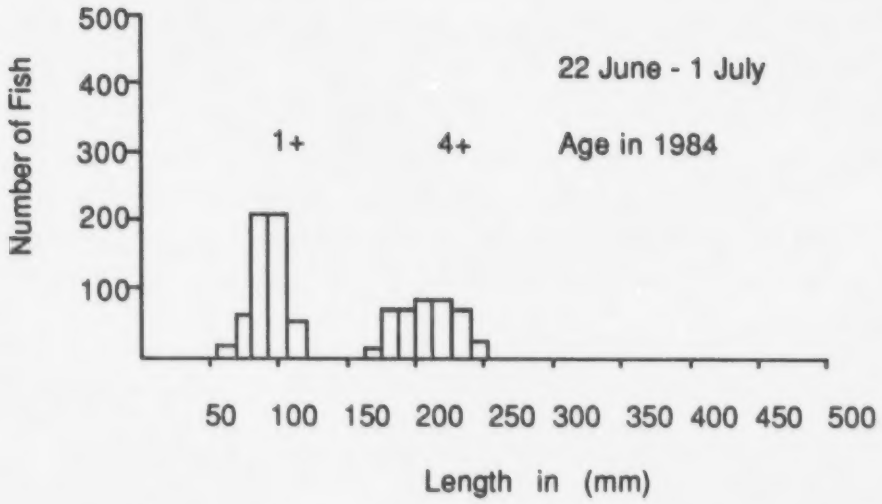


Figure 13. Length frequency of Arctic cisco in Prudhoe Bay at the start of the 1984 season (22 June to 1 July).

It should be noted that breach effectiveness is also directly related to other causeway-induced changes. In the case of West Dock, the major blockage to longshore movement results from strong causeway-induced intrusions of marine water, and if this cold and marine water extends to the base of the causeway then the breach would be ineffective because few fish would be in the area due to the relatively adverse marine conditions.

In contrast, the two breaches in the Endicott causeway are used extensively by fish, especially broad whitefish and Arctic cisco. These breaches are wider (61 m and 152 m wide for the nearshore and the offshore breaches, respectively) and constructed with wing dams to prevent silting. If the breaches were not present, then in order to move across the delta, fish would be required to pass around the causeway through cold, marine waters, a route they might not exploit because of their aversion to such conditions. For example, broad whitefish were observed passing around the causeway when low salinity water was available but when more saline conditions dominated north of the causeway, they appeared to make ready use of the breaches (Gilbertson et al. 1987).

Thus the effectiveness of a causeway breach depends on several factors (e.g. type of habitat and species of fish utilizing the area ect.), and a breach design and placement that is effective for one causeway may not be effective for all causeways.

Potential Benefits of Causeways

Generally, it is thought that causeways affect fish in only negative ways, e.g., by blocking migrations or adversely effecting favoured habitat. However, there are some potentially beneficial effects of causeways. We know little about potential benefits because all major studies have been designed to study only negative effects.

The marine upwellings and intrusions that are exacerbated by West Dock can enhance the shoreward flux of marine prey. The area of intense marine intrusion that lies immediately west of West Dock causeway has been consistently characterized by having the highest abundance of the major epifauna prey for fish (Moulton et al. 1986). This is because the epifauna transported into the nearshore area tends to remain in the area even after marine conditions have dissipated (Griffiths and Dillinger 1981). Consequently, these zones have the potential for becoming prime feeding areas. An apparent increase in least and Arctic cisco numbers at the eastern end of the barrier island-lagoon complex may reflect exploitation of these rich food resources (L. Moulton pers. comm.). However, such areas may be of limited value since fish may only be able to exploit them during periods of warm, low-salinity waters.

Whether causeway-induced intrusions increase prey abundance throughout the nearshore zone is a matter of conjecture and current debate. The effect of both the West Dock and Endicott causeways on prey distribution is linked to the impacts these structures have on local hydrography. Under east winds strong marine upwellings occur along the western face of both structures. Biomass levels of the important epifaunal prey species also tend to be greatest in these areas (Moulton et al. 1986; Cannon et al. 1987b). Thus, the same causeway-induced upwellings that cause a physical deterioration in the nearshore habitat of anadromous fish (higher salinity, lower temperature) also tend to be rich in prey. High prey concentrations in the immediate vicinity of the causeways may also reflect low energy zones in which detritus and their associated epifauna collect.

SUMMARY

The nearshore oceanography of the central Alaskan Beaufort Sea is influenced by air temperature, wind direction and velocity, precipitation, ice cover, river discharge and solar radiation. Typically, northeast winds raft surface waters offshore and subsurface

marine waters onshore, causing a lowering of water levels and intrusions of cold, marine bottom water. Northwest winds have the reverse effect.

Under northeast winds, the presence of West Dock intensifies the marine intrusion along its west side, while the warm brackish buoyant plume of the Sagavanirktok River builds up on its east side before flowing around the tip of the causeway. The presence of the Endicott causeway results in a small marine upwelling just west of its seaward tip, while an area of intense upwelling occurs just offshore. Under northwest winds, the Colville and Kuparuk plumes flow around West Dock, while a weak marine intrusion occurs along its east side. This warm brackish surface water merges with the Sagavanirktok River plume and continues east around the Endicott causeway.

Between 1981 and 1986, four anadromous species (Arctic and least cisco, Arctic charr and broad whitefish) and two marine species (Arctic cod and fourhorn sculpin) have accounted for between 95 and 98% of all fish taken by fyke net.

Least cisco, originating from the Colville River and points west, undertake summer feeding migrations that extend east of the Sagavanirktok Delta. After feeding in the Prudhoe Bay/Sagavanirktok Delta region for most of the open-water period, they return to overwintering and/or spawning areas in the Colville River and points west.

Alaskan Arctic cisco are believed to migrate over from the Mackenzie River as age 0^+ fish (Gallaway et al. 1983). Once in Alaskan waters they take up residence in the Colville and Sagavanirktok deltas and only return to the Mackenzie River when they are ready to spawn. Large (>250 mm FL) Arctic cisco disperse along the Beaufort Sea coast to feed during the open-water period. Small (>250 mm FL) individuals tend to have a more limited distribution pattern, except for the age 0^+ fish during the westward migration.

Arctic charr collected in the Prudhoe Bay/Sagavanirktok area are probably Sagavanirktok River stock. These fish enter nearshore water at breakup and disperse along the Beaufort Sea coast to feed. Most large charr have returned to their overwintering and/or spawning areas by early September, and most small individuals by late September.

Broad whitefish in the Prudhoe Bay/Sagavanirktok Delta region are Sagavanirktok River stock. They tend to remain in brackish water in close proximity to freshwater drainages during the open-water season, and typically overwinter far enough upstream in the Sagavanirktok River to stay out of the influence of the winter marine intrusion.

Fish habitats along the Alaskan Beaufort Sea coast vary and consist of barrier island-lagoon systems, river delta, bays, exposed coastlines and nearshore ice edges. The primary importance of these nearshore habitats to anadromous fish is for feeding, since fish prey densities are much higher in these habitats than in freshwater habitats. Epibenthic organisms (e.g. mysids and amphipods etc.) are the major food items for anadromous fish. These prey items re-occupy the nearshore habitats from deeper offshore waters each spring and must be continuously replenished throughout the open-water season to maintain an abundant food supply.

The three most important physical characteristics determining habitat use are temperature, salinity and current. Temperature and salinity tolerances of the four key species vary, with the tolerances of Arctic charr > Arctic cisco > least cisco > broad whitefish. Currents are most important for small Arctic cisco which are carried by prevailing currents during their migration from Canada.

The distribution patterns and movements of large (>250 mm FL) least cisco do not appear to be affected by the presence of either West Dock or the Endicott causeways. Small (<250 mm FL) least cisco can be blocked from moving into Prudhoe Bay by West Dock causeway during periods of strong northeast winds due to the intense upwelling on the west side of the causeway. Too few small least cisco disperse as far

east as the Endicott causeway to provide adequate data from which to make an assessment of impacts.

The distribution patterns and movements of large Colville and Sagavanirktok Arctic cisco do not appear to be affected by either the West Dock or the Endicott causeways. However, small Colville Arctic cisco could be blocked from entering Prudhoe Bay by West Dock. The Endicott causeway appears to have little effect on small Arctic cisco from either the Sagavanirktok or Colville rivers.

West Dock and the Endicott causeways have little effect on either large or small Arctic charr, since individual fish spend little time during the open-water season in the Prudhoe Bay/Sagavanirktok Delta area.

West Dock does not appear to be a barrier to the along shore movement of large and small broad whitefish because of their limited dispersal pattern and the fact that the causeway is not located on a major migratory pathway used by this species. There is no evidence that the movements of large and small broad whitefish are affected by the Endicott causeway, since they use the two breaches to move across the Sagavanirktok Delta.

To date there do not appear to be any population level effects for any of the four key anadromous species. However, the potential for population effects exists for Arctic cisco, if the percentage of the Mackenzie River population that is recruited to Alaska each year is high or if the fish are from a single Mackenzie stock.

PART 2: POTENTIAL EFFECTS OF CAUSEWAYS AT KING POINT AND STOKES POINT ON THE YUKON COAST

INTRODUCTION

The possible construction of shore-based facilities, docks and causeways, along the Yukon coast has raised concerns about adverse impacts on the anadromous fish that use the region during the open-water season. The primary concern is whether solid-fill causeways would have adverse effects on the fish stocks in the region. King Point and Stokes Point have been identified, for the purpose of this study, as potential sites for shore facilities, eventhough the Stokes Point site is located within the boundries of the North Yukon National Park and causeway. Since detailed plans for these developments are unavailable, we have based our assessments on hypothetical causeway designs that incorporate aspects of several proposals that have been put forward by industry and government agencies.

In this section of the report, we provide a description of current knowledge on important anadromous fish and physical oceanography in the regions of the projected developments. We then describe the potential effects that these structures could have on the key fish species. These speculations are based on the available data from the Yukon coast and from the Alaskan experience.

STUDY AREA AND PROPOSED DEVELOPMENTS

The two sites, Stokes Point and King Point, are located on the Yukon coastal Plain, an area of low relief (0-150 m above sea level) that lies between the coastal Richardson Mountains and the Beaufort Sea (Fig. 14). The coastal plain extends from the Mackenzie River delta westward to the Alaska-Yukon border, and varies in width from 5 km near the border to about 30 km in the vicinity of King Point (McDonald and Lewis 1973).

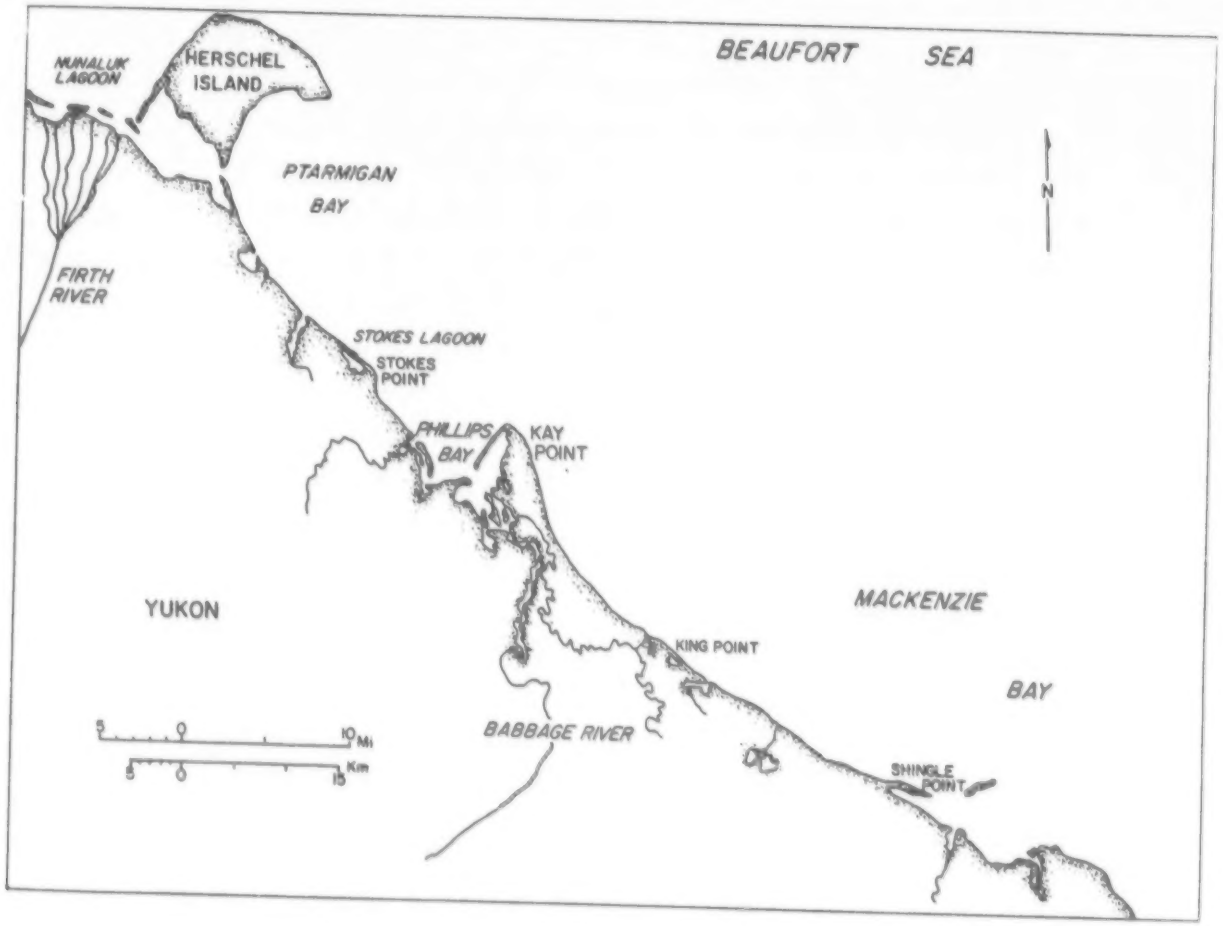


Figure 14. Yukon coast from Shingle Point, Herschel Island. The two sites, King Point and Stokes Point are shown.

Stokes Point

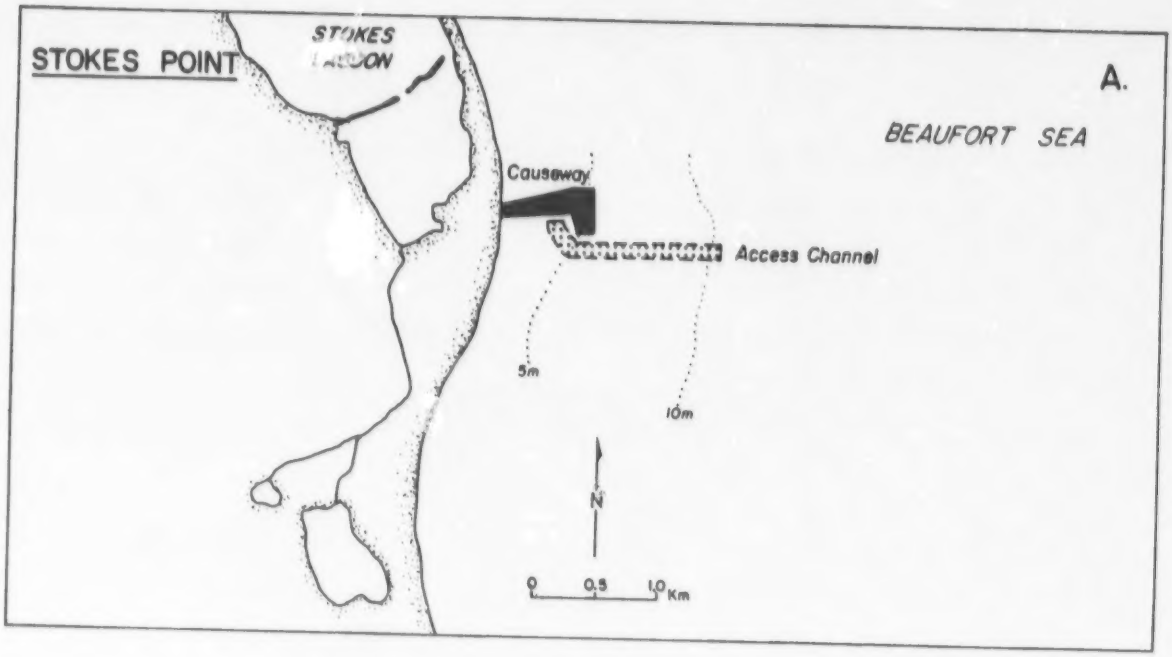
Stokes Point, the most westerly of the two sites, lies along a relatively low-lying section of coastline that is backed by 8-10 m high bluffs located about 50-100 m from the beach. The beaches are narrow and relatively steep. At the point itself, a spit has advanced in a southeasterly direction to totally enclose a shallow, marshy lagoon (Fig. 15A) (McDonald and Lewis 1973). The nearshore depth profile off Stokes Point shows a smooth concave bottom out to at least 10 m depth. Water depths increase with distance from shore more rapidly than in the Prudhoe Bay/Sagavanirktok Delta region (e.g. 10 m depth at 1.5 km at Stokes Point vs. 3 m at 1.5 km in the Prudhoe Bay area).

The hypothetical development for the Stokes Point area is shown in Figure 15A. The plan calls for a solid-fill causeway, approximately 700 m in length and 150 m in width, extending from shore out to the 5 m depth contour, then extending 400 m to the south. In addition, a dredged access channel 10 m deep, 1.3 km in length, and 100 m in width, would extend from the causeway out to the 10-m depth contour.

King Point

King Point, located about mid-way between the Mackenzie Delta and Herschel Island, is the other development site (Fig. 15B). This section of the Yukon coast is characterized by steep cliffs (30-50 m) with very narrow or non-existent beaches. At King Point itself, a gravel bar about 100 m in width has completely enclosed a small lagoon. Water depth at King Point increases rapidly with distance from shore (e.g. 10 m depth at 1 km, and 20 m at 2.2 km).

The hypothetical development at King Point is located at the western end of the lagoon, just east of the steep cliffs (Fig. 15B). The facilities would include a solid-fill causeway about 1000 m in length and 100 m in width, extending from shore out to the 10 m depth contour, then extending about 100 m to the southeast. A breakwater approximately 1000



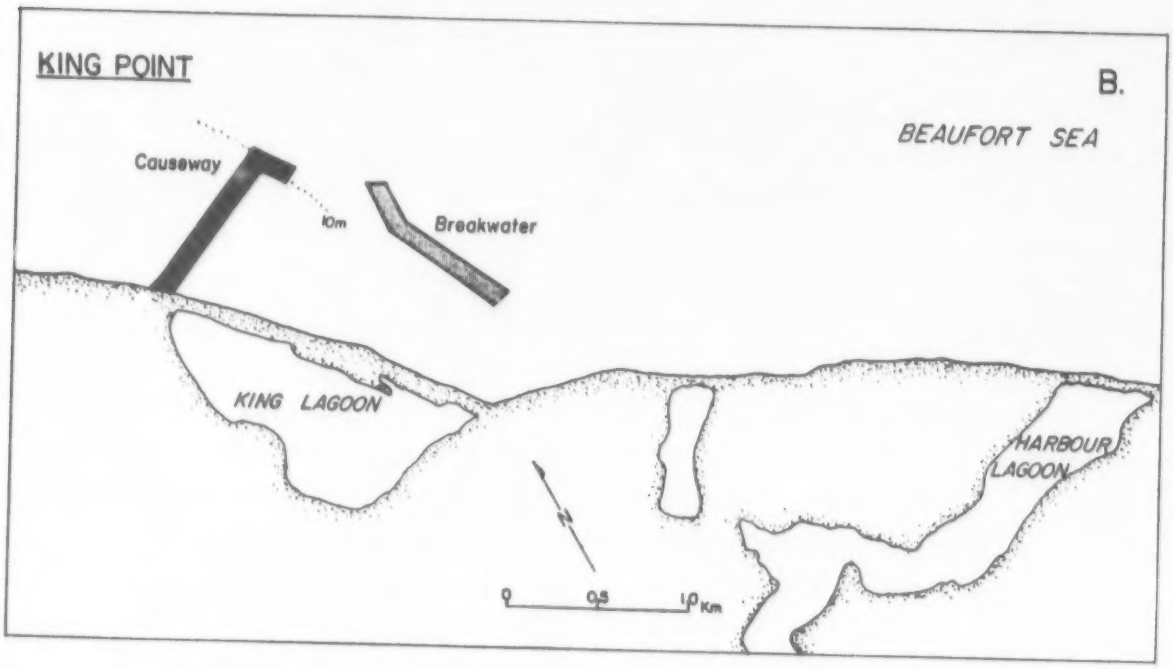


Figure 15. Map of (A) Stokes Point and (B) King Point showing proposed developments at each site. Lines associated with depth numbers are approximate depth contours.

m in length and 100 m in width would be located to the east of the causeway.

PHYSICAL PROCESSES

Although the nearshore hydrography of the Yukon coast is determined by a number of different factors, the physical processes can generally be explained in terms of wind regimes, river discharge and sea ice conditions.

Wind

Winds along the Yukon coast exhibit more variability than in other coastal regions of the Beaufort Sea. There are three dominant wind conditions (Fig. 16):

1. Easterly winds associated with high pressure systems over the Arctic Ocean occur most frequently. These winds result in westward movement of coastal waters, and can cause upwelling of cold, saline marine water at exposed coastal locations.

2. Northwesterly winds occur less frequently but are often comparatively strong and result in large coastal currents flowing in a southeastward direction along the coast. These winds result in downwelling conditions along the Yukon coast.

3. Southwesterly winds blowing directly offshore, referred to as fohn winds, result from downslope air flow over the Richardson Mountains (Burns 1973), located within the interior of the Yukon, and can result in intense winds extending as much as 50 km from shore. The strong southwesterly winds are most intense in the vicinity of Shingle and King Points, and are seldom observed further west at Herschel Island. These winds would be less prevalent at Stokes Point than at King Point. These winds displace surface waters offshore and result in localized upwelling between Kay Point and Shingle Point (Bradstreet et al. 1987).

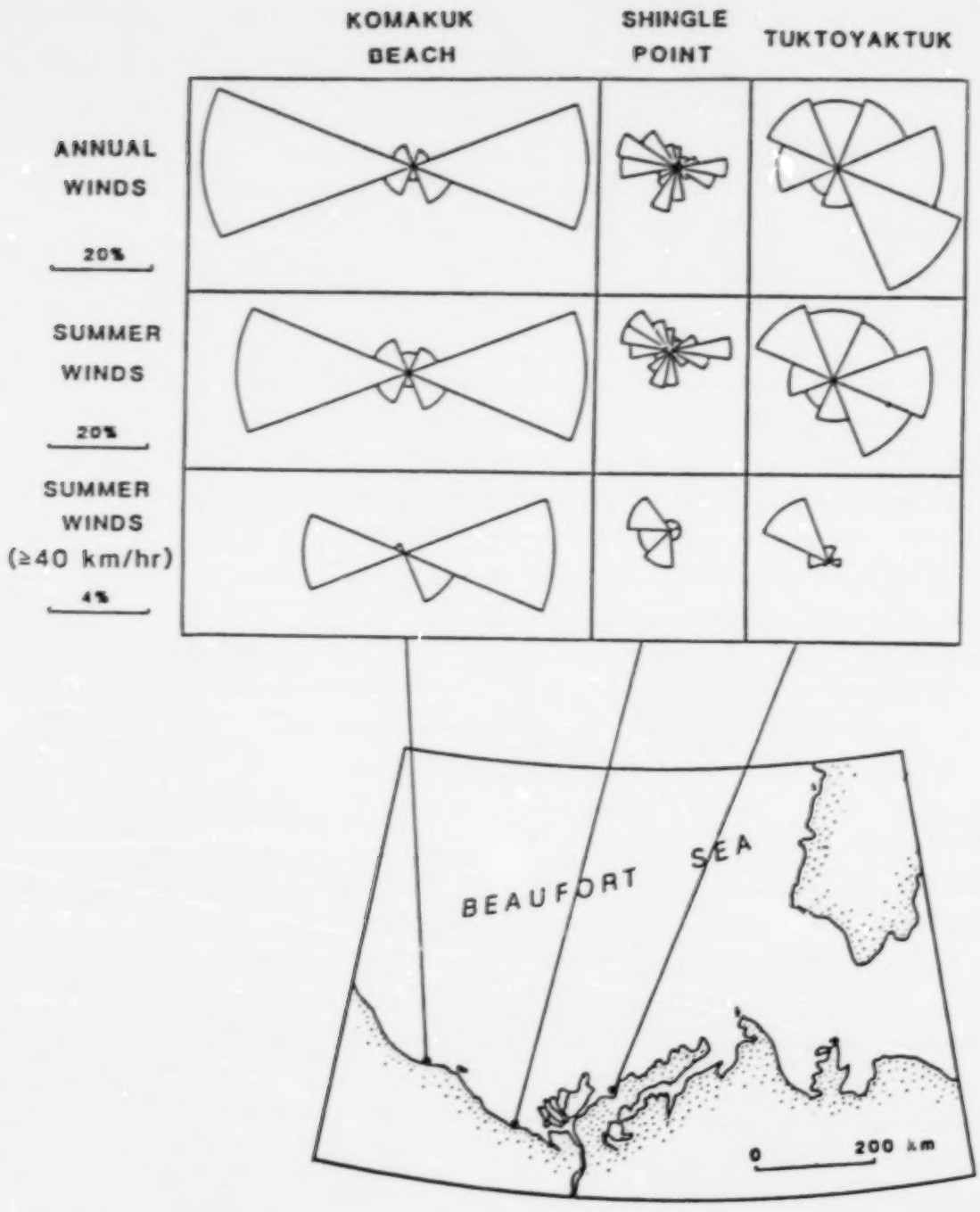


Figure 16. The directional distribution of winds at stations along the Beaufort Sea coast (from Harper and Penland 1982). The number of years of data used in constructing these distributions is not stated.

Upwelling events of this type often occur when the winds in other areas are blowing from the west to northwest, conditions that favour downwelling.

River Discharge

The Mackenzie River is the most important river affecting regional oceanographic conditions. It accounts for over 95% of the total run-off discharge into the Canadian Beaufort Sea. The effects of the three largest Yukon drainages, the Firth, Babbage and Blow rivers, are limited to localized areas.

Because the study area is located approximately 90 km east of the nearest Mackenzie River distributary in Shallow Bay, discharge water undergoes considerable mixing and dispersal prior to reaching this portion of the Yukon coast. The brackish-water layer or diffuse plume (Thomson et al. 1986) originating from the Mackenzie River covers a broad area off the Yukon coast, typically having a width of 10 km or more (Fig. 17). It often follows the coast westward to Kay Point, but then is displaced offshore along the shelf edge past Herschel Island. Oceanographic conditions in the large embayment between Kay Point and Herschel Island thus tend to be influenced more by local discharge conditions than by the Mackenzie River plume (Fissel et al. 1987a, 1987b).

The influence of the Mackenzie River on the Yukon coast varies both within and among years. The extent of sea-ice dispersal in early July controls the dispersal of Mackenzie River water and often determines the range of plume salinities for the remainder of the open-water season (Thomson et al. 1986). In years when large amounts of ice clear the area by early July (e.g. 1980 and 1982), salinities are higher than average in the Mackenzie River plume. Conversely, during years of very limited ice clearing in the early season (e.g. 1984 and 1985), plume salinities are much lower. The within-season variability arises, in large part, from wind patterns, particularly the balance between easterly and westerly wind regimes. Prolonged periods of westerly winds

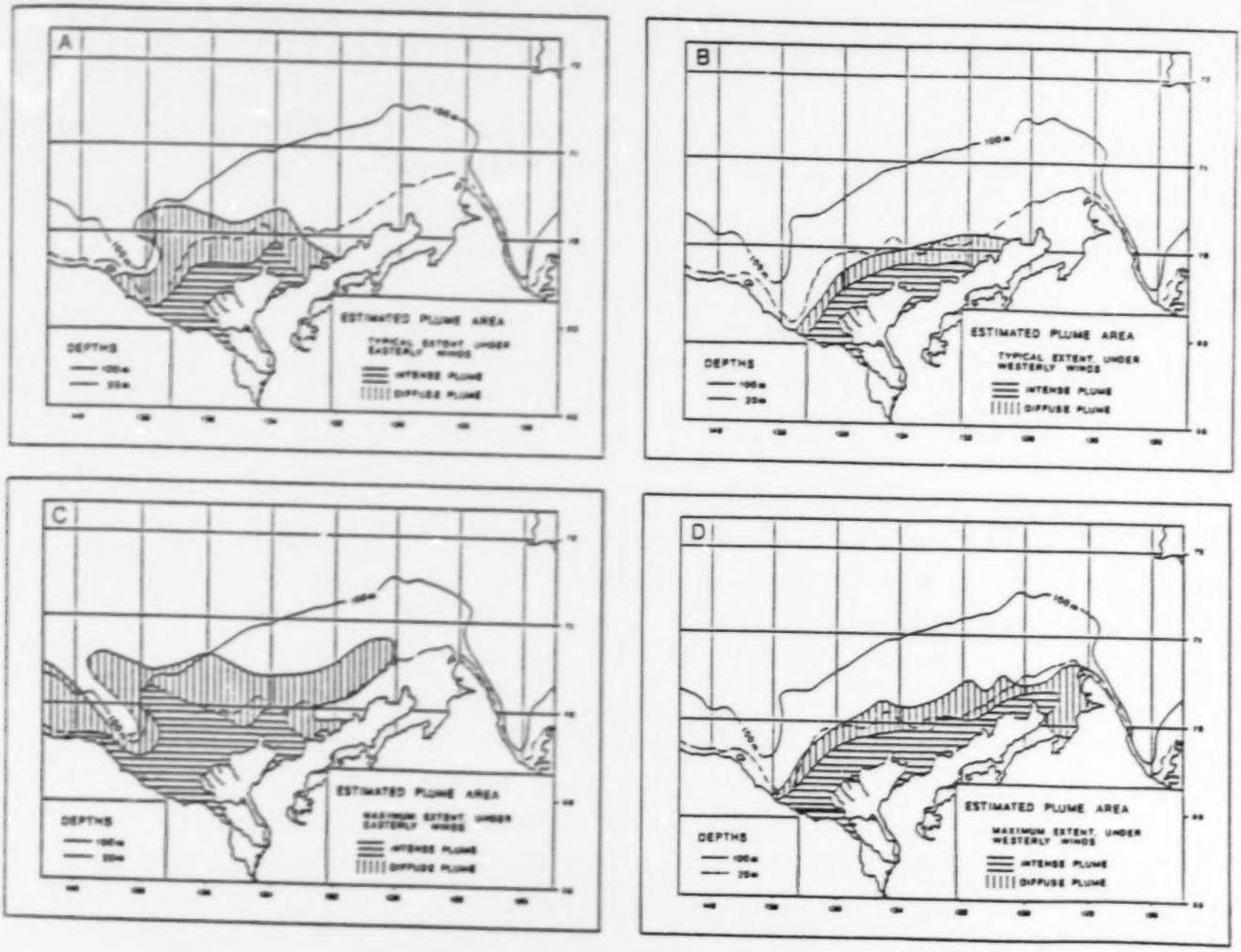


Figure 17. The extent of the Mackenzie River plume, as shown in the 1980 to 1983 satellite imagery data, under dominant west-northwesterly and southeast-northeasterly wind conditions. (A and B) are estimated typical conditions, while (C and D) are estimated maximum extent of the plume (adapted from Thomson et al. 1986).

drive the Mackenzie River plume to the east, away from the Yukon coast, whereas prolonged easterly winds bring the Mackenzie waters into the study region. However, strong easterly wind events also induce coastal upwelling which tends to move the plume offshore.

Of the three largest Yukon rivers, only the Babbage River is likely to influence the Stokes and King Point areas significantly. The Babbage River delta is approximately 15 km from Stokes Point and 30 km from King Point (see Fig. 14). River discharge probably results in brackish water reaching the Stokes Point area under easterly winds. However, the effect on King Point will probably be reduced, given its greater distance from the Babbage River and the greater extent of exposed coast where mixing can occur.

Peak discharges from the Babbage River occur about one to four weeks later than for the Mackenzie River. Throughout the summer, the discharges of the rivers in the region are highly variable depending on total precipitation within their respective drainage basins.

Sea-Ice Conditions

By May, the shorefast ice formed during winter off the Yukon coast reaches a maximum offshore extent of 10 to 50 km. Breakup and dispersal in Mackenzie Bay begins during the first half of June when Mackenzie River discharge over-floods the shorefast ice. At about the same time, local melting also occurs in the vicinity of major Yukon River estuaries, particularly the Babbage River. In most years, landfast ice breaks up and disperses between mid-June and early July.

Heavy concentrations of sea-ice can remain off the Yukon coast throughout the summer, depending on the proximity of the pack-ice. The location of the pack-ice can vary enormously, particularly in July (Fig. 18). In some years (e.g. 1974, 1975 and 1985) the occurrence of the pack ice edge south of 70° N off the Yukon coast results in intrusions of sea-ice floes along coastal areas throughout much of July. In most years, the pack-ice retreats offshore as the summer progresses.

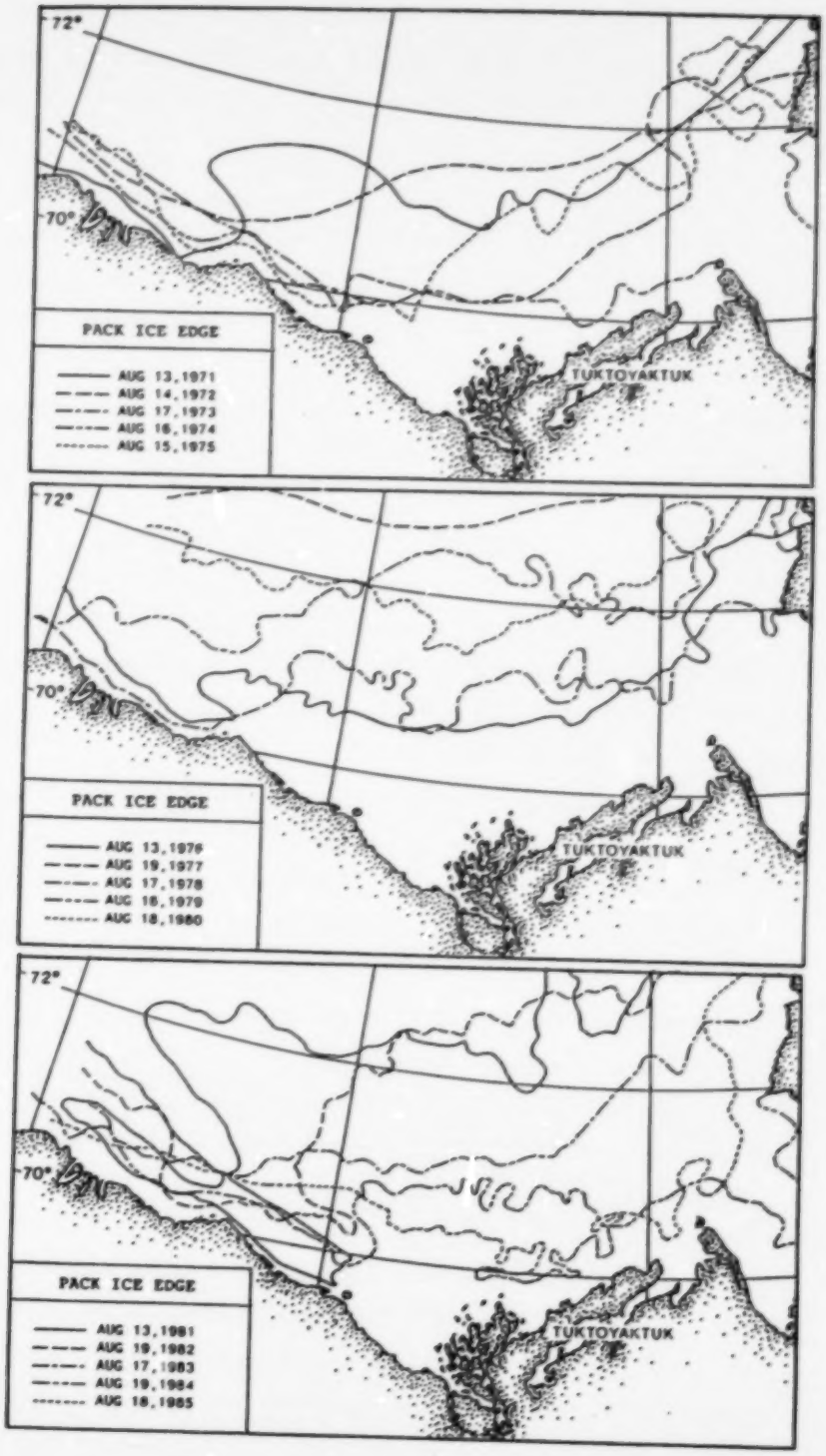


Figure 18. Mid-July locations of the ice edge from 1971 to 1985 inclusive. The pack ice edge is defined as the edge of seven-tenths sea-ice cover (adapted from Fechhelm and Fissel 1988).

However, strong westerly winds of extended duration can reverse this process at any time during the summer and bring sea-ice into the Yukon coastal region from eastern Alaska.

New ice typically begins to form in late September and early October, although freeze-up can begin earlier if winds keep the pack-ice comparatively close to shore. New ice growth is most rapid around the edge of the pack-ice and in sheltered coastal areas. Open water in the nearshore area is rarely observed after October, as the landfast ice begins to stabilize and extend offshore.

Oceanographic Conditions

Oceanographic data available in the vicinity of King and Stokes Points were reviewed (Table 5) and selected data sets were analyzed to investigate the water mass characteristics in these nearshore areas. However, the available data were not adequate to provide a full description of the natural oceanographic conditions in these areas due to:

1. the limited number of stations sampled in water depths of 10 m or less. The wide separation between stations makes it impossible to resolve horizontal gradients (i.e., fronts) over distances of less than a few km;

2. the paucity of measurements in July, particularly for the King Point area; and

3. the absence of repeated measurements over extended periods, as most data sets were collected over periods of one day to one week. The data collected by Bond and Erickson (1987) at two sites off Stokes Point provided the best set of repetitive measurements at approximately one week intervals. However, even these stations were not sampled intensively enough to fully establish the

Table 5. Summary of available nearshore oceanographic data off King and Stokes Points in summer.

Dates	Data Set No. (see Birch et al. 1987)	No. of Stations King Pt.	Stokes Pt.	References
31/08/60	60-0003	1	-	Grainger and Lovrity 1975
13/07/72 06/08/72	72-0118	-	3	Mann 1974
23/07/73 12/09/73	73-0023	-	4	Mann 1974
30/07/74 24/08/74	74-0021	1	1	Kendel et al. 1975
17/07/75 07/08/75	75-0025	3	3	Kendel et al. 1975
20/08/80 06/09/80	80-0025	3	-	Griffiths and Buchanan 1982
04/08/82 06/08/82	82-0095	5	7	Allan and Mackenzie-Greive 1983
02/08/83 04/08/83	83-0047	-	7	Allan and Mackenzie-Greive 1984
01/08/84 07/08/84	84-0049	5	7	Davidge and Mackenzie-Greive 1986
09/07/85 19/08/85	n/a	-	2(a)	Bond and Erickson 1987
26/08/85 28/08/85	85-0007	2	-	Bradstreet and Fissel 1986
24/07/85 08/09/85	85-0017	-	4	Hopky et al. 1986
30/08/85	85-0030	2(b)	-	Dr. P. Hill, BIO (pers. comm., 1988)
06/09/86 07/09/86	86-0004	1	1	Bradstreet et al. 1987

(a) Repeated weekly throughout observation period.
(b) Temperature data from moored current meter in 5 and 10 m water depths.

response of oceanographic conditions to wind shifts, which can occur over periods as short as 2-4 days.

Surface oceanographic conditions derived from 1980 to 1986 satellite data sets were also examined (Borstad 1985; Thomson et al. 1986; Bradstreet and Fissel 1986; Bradstreet et al. 1987). While useful in determining the regional distribution of water masses, the satellite data suffer from too imprecise a spatial resolution (1-2 km) to adequately resolve important horizontal gradients which can occur over a few hundred metres in the coastal zone.

Stokes Point

The most complete data sets available for Stokes Point were the short duration measurements of 1975, 1982, 1983, and 1984 (Table 5), and data collected over an extended period in 1985 (Bond and Erickson 1987). Excluding 1982, the observed range in surface temperature was 3 to 9 ^{o}C and surface salinity was <1 to 18 ppt. In these years, cold saline Arctic water was present in the area at depths exceeding 5 to 8 m. Conditions in 1982 differed from those in other years due to the occurrence of very high salinities (29 to 32 ppt) at the surface in early August. These high salinities apparently were the result of prolonged westerly winds which drove the brackish water from both the Babbage and the Mackenzie rivers eastward, leaving saline Arctic water throughout the water column. As described below, a similar situation occurred at King Point at the same time.

The extended observations from 29 June to 19 August 1985 collected by Bond and Erickson (1987) off Stokes Point are particularly valuable as they provide insight as to the differences in water properties within the coastal zone (Fig. 17). Through July, the coastal water was brackish (salinities: 1 to 4 ppt) at the surface, with only moderately greater salinities at 5 m depth (4 to 9 ppt). Surface temperatures increased through the month from 3 to 7 ^{o}C. These water properties were likely the result of river discharge and to a lesser degree the effects of ice melt. From 5 to 12 August, conditions changed dramatically, with

much colder, more saline water occupying the lower portion of the water column along the 5 m contour. A sharp increase in salinities was also noted at the shoreline stations, but not until 9 August. These changes were caused by strong easterly winds from 5 to 7 August and moderate easterly winds from 10 to 12 August and are consistent with coastal upwelling driven by easterly winds. By 19 August, the surface waters at the 5 m contour and at the shore had become more saline and cooler. This change followed strong northwesterly winds of 15 to 16 August, which may have driven cold Arctic water located further west into the Stokes Point coastal area (cf. Bradstreet and Fissel 1986; 18 August 1985 satellite imagery).

Differences in water property measurements between shore and 5 m deep suggest that the differences are generally comparatively small. For six pairs of concurrent measurements, the maximum difference in surface temperature was 2 °C, while the maximum salinity difference was 1 ppt. No data were available on the size of the horizontal gradients beyond the 5 m depth contour in the coastal zone, for example, to the 10 m depth where a causeway could possibly end.

In summary, large time-dependent variations in water mass characteristics occur at Stokes Point, with roughly the same magnitude as those observed at King Point (see below). These changes can occur over periods of a few days or, in dramatic events, several hours. Easterly winds tend to move riverine water into the study area, but can also induce shallow coastal upwelling, bringing cold, saline Arctic water into the coastal zone. Northwesterly winds advect waters from the west and further offshore into the Stokes Point area. These waters are generally cold and saline. However, in years of prolonged easterly winds, large amounts of brackish water of Mackenzie River origin may be present along the edge of the narrow continental shelf off the Yukon coast. Under these conditions northwesterly winds can bring this water into the Stokes Point area. It is thus apparent that a wide range of hydrographic conditions can occur for either of the dominant wind directions.

King Point

The temperature-salinity data examined from four years (i.e., 1975, 1980, 1982, 1984) revealed surface temperatures ranging from 6 to 14 °C over the mid-July to late August period. Observed salinities in three of the four years were fairly low (8 to 15 ppt), but were markedly higher in early August of 1982 (30 to 32 ppt). The higher 1982 salinities are consistent with the absence of the Mackenzie River plume along the Yukon coast due to prolonged westerly winds in the latter half of July and early August (Thomson et al. 1986). The lowest salinities observed were in 1980 when the plume of the Mackenzie River extended westward along the Yukon coast as a result of prolonged easterly winds (Thomson et al. 1986; Borstad 1985). The water at depth, was typically colder and more saline and was separated from the upper layer by a strong pycnocline at depths ranging from 3 to 7 m.

Analysis of Satellite imagery from 1985 and 1986 (Bradstreet and Fissel 1986; Fissel et al. 1987a) suggests that considerable variability in oceanographic conditions occurs, even during wind conditions that would generally favour the presence of the warmer, less saline Mackenzie River water off King Point. In 1985, easterly winds resulted in the development of extensive upwelling conditions, with surface water temperatures plummeting from 5-6 °C to less than 2.5 °C between 20 and 28 August. A similar pattern occurred in early September of 1986 when an expanding area of cold Arctic Water developed along the coast, apparently in response to local southwesterly winds from Kay Point to Shingle Point (Fig. 19). In both cases, the satellite data were inadequate to determine whether the cold, saline water extended to the shore or if a remnant of warmer, less saline water remained within the narrow (<1 km wide) band of coastal waters having a depth less than 10 m.

Further evidence of the extent of short-term variability in oceanographic conditions off King Point is provided by near-bottom measurements of temperatures obtained at 5 m depth from 30 August to 6 September 1985 (Fig. 20). In this case, temperatures decreased by 5 °C

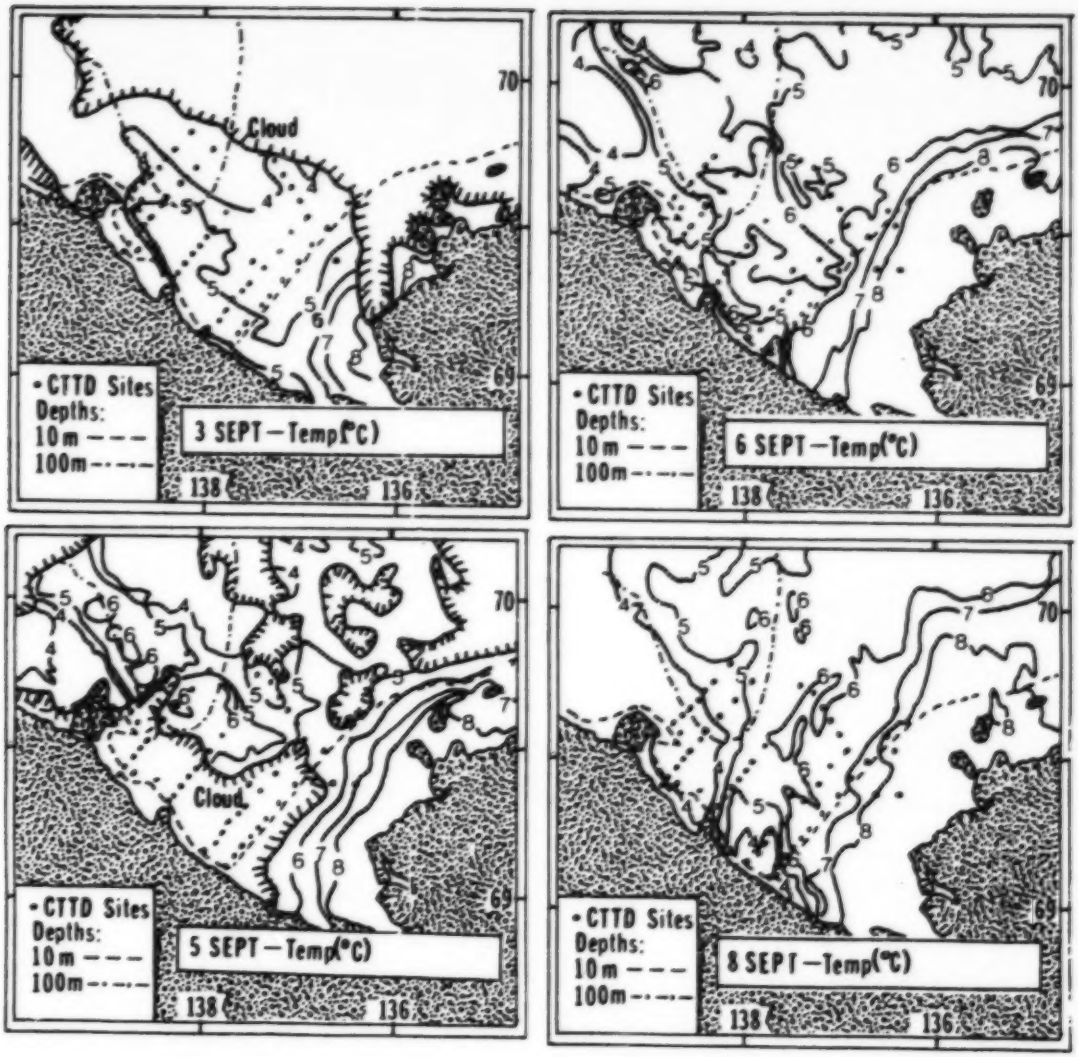


Figure 19. Maps of surface temperature (°C) on 3, 5, 6 and 8 September 1986 off the Yukon coast. Based on AVHRR satellite data (adapted from Fissel et al. 1987a).

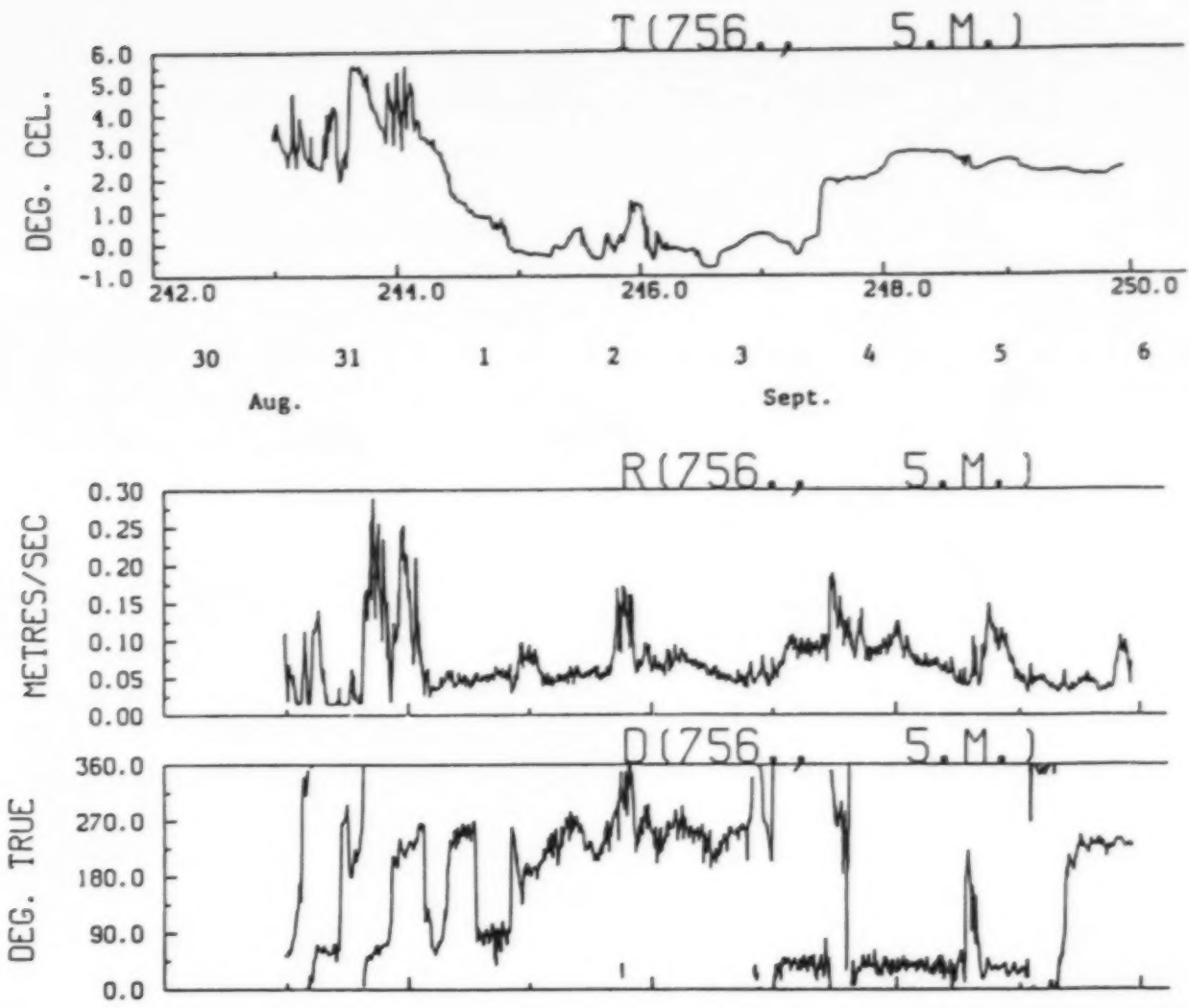


Figure 20. Measurements of temperature, current speed and direction at 5 m depth off King Point 30 August to 6 September 1985 (adapted from Dr P. Hill, Bedford Institute of Oceanography).

over a period of one day on 1 September (= day 244 in Fig. 20), and then increased by 3° C over a few hours on 3 September, in direct response to shifts in wind and current directions.

In summary, a review of existing oceanographic observations suggests that large time-dependent variations occur at King Point. The conditions are particularly variable under easterly winds when Mackenzie River plume waters can occur immediately adjacent to the coast or be displaced offshore, due to upwelling. The transition to upwelling, or relaxation from it, results in large temperature and salinity changes over periods of a few days or less. Most importantly, it is not known whether upwelling extends up to the beach or if a narrow band of warmer water persists along the coast. In addition, very little information is available on the characteristics or spatial distribution of water masses during prolonged periods of westerly wind conditions.

Effects of Causeways on Oceanography

The effects of the hypothetical causeways on the physical processes would be similar at Stokes and King Points. In both cases, brackish river water originates to the east of each site, while waters to the west are relatively colder and more saline. As stated above exceptions to this do occur, since oceanographic conditions depend not only on the wind conditions at a given time but also on the recent wind history. Within this conceptual framework, the potential effects of these causeways are discussed below.

1. Disruption of the westward transport of brackish coastal water under easterly wind conditions. As has been observed for Alaskan causeways, colder, more saline water is likely to appear at the end of the causeway and replace the normally brackish water on the downwind (western side) of the causeway. This will create a pool of comparatively cold, saline water which may persist until a major wind reversal.

2. Under westerly or southwesterly wind conditions, cooler more saline water west of each structure would be transported east resulting in relatively uniform conditions on both sides of the causeways. However, it is possible that surface divergence and the strong flows around the end of the causeways may result in localized upwelling. In the unlikely case that the water being advected along the coast is brackish, this may modify water properties by producing a pool of cold saline water on the east side of both causeways. Unlike the Alaska situation, where warmer brackish water is confined shoreward by barrier islands, this situation is unlikely to occur off Stokes and King Points.

3. The causeways may also alter the timing of breakup and freeze-up in the immediate vicinity of the causeway. In the early summer, the causeway would block the alongshore movement of ice floes, increasing ice conditions temporarily. In view of the natural variability of wind forcing, this effect would generally be limited to a few days. However, the effect could be of greater duration at King Point, where the breakwater to the east of the causeway could prove to be a greater impediment to ice dispersal.

During freeze-up, it is likely that ice crystals may accumulate along the causeway, particularly on the western side. As is the case for Alaska, the effect is likely to be greatest for westerly winds that transport cold water onshore. Gilbertson et al. (1987) estimated that ice formed one or two weeks earlier on the westward side of the Endicott causeway than normally would have been the case.

While causeways at either Stokes Point or King Point will inevitably result in a disruption of natural temperature, salinity and current conditions, the magnitude of the disruptions cannot be determined quantitatively, given existing information. It seems likely that the effects would be less extensive than those in the Alaska situation, given the smaller size of the Yukon structures (about 1/4 the size of the Alaskan structures). Thus the disruption in flow patterns would be less than in Alaska, although the more complicated structure of

the King Point development is prone to larger alterations in current flows. Another factor of considerable importance is the extent of horizontal changes in temperature and salinity patterns in relation to causeway size. In Alaska, large horizontal differences in water properties occur over the length of the causeways, resulting in the potential for considerable alterations in flow patterns. Existing data do not permit a similar determination of the horizontal temperature and salinity gradients for the Yukon situation. However, the natural variability in water properties with time appears to be larger off the Yukon coast than in Alaska, suggesting that effects of the causeways may be more variable.

In summary, the potential effects of Yukon causeways on oceanographic processes can be identified qualitatively, using the Alaskan studies as a guide. However, quantitative estimates of effects require more extensive oceanographic data than are presently available.

BIOLOGICAL SETTING

Description of the biological environment along the Yukon coast is based primarily on the works of Mann (1974), Griffiths et al. (1975), Kendel et al. (1975), Baker (1986), Bond and Erickson (1987) and Bond (1987). Unlike the Prudhoe Bay studies where fyke nets were the primary sampling device, all the surveys carried out in nearshore waters (<5 m depth) of the Canadian Beaufort Sea have used gill nets and seine nets, except Bond (1987), who used fyke nets. The difference in technique is significant since fyke nets sample a larger range of size-classes than gill nets which tend to capture mainly large fish and seines which capture only small ones. The following section reviews knowledge of the fish community along the Yukon coast and includes discussions of the migratory patterns, coastal distribution, and habitat use of the key species of anadromous fish.

General Description of Fish Community

Approximately nineteen species of freshwater, anadromous and marine fish have been collected by gill net along the Yukon coast (Table 6). Although abundances vary with year and location, three anadromous species, Arctic and least cisco and Arctic charr, have accounted for an average of 87% (range: 66 to 98%) of the total catch, while only one marine species, fourhorn sculpin, has been consistently represented (Table 6). The only seining data collected over a complete open-water season along the Yukon coast was at Phillips Bay (Bond and Erickson 1987). Arctic and least cisco and Arctic charr comprised 66% of the small fish (<250 mm FL) caught, followed by fourhorn sculpin (30%), Arctic flounder (2%) and boreal smelt (3%). A single set of fyke net data was collected at Phillips Bay in 1986 (Bond 1987). The results showed that anadromous species accounted for most of the catch (59.2%), followed by the marine species (40.7%) and the freshwater group (0.1%). Within the anadromous group, Arctic and least cisco and Arctic charr comprised 88.9% of the catch, followed by rainbow smelt (9.4%), broad whitefish (1.1%) and lake whitefish (0.5%).

A comparison of the Phillips Bay gill net and seine data from 1985 with fyke net data from 1986 reveals major differences in catch among the gear types (Table 7). The most obvious difference was in the number of fish caught, 142,797 in fyke net versus 13,030 in the seine and gill nets. This difference was due to the fact that the fyke nets fished almost continually through the open-water season, while the gill nets and seines were fished on a weekly basis. On a percentage basis, more marine fish (40.7% of the total catch) were captured in fyke nets than had been taken by gill nets (24.6%) or seines (31.1%), while the reverse was true for anadromous fish (Table 7). However, the most important difference was in the number of small (<250 mm FL) Arctic and least cisco collected. Fyke net data showed that these small individuals, particularly Arctic cisco, were much more abundant, in terms of numbers, in the region than had been shown in gill net and seine studies (Table 7).

Table 6. Species composition (percent) of fish caught in gill nets along the Yukon Beaufort Sea coast 1974 through 1985.

Species	Shingle Point		King Point		Phillips Bay			Stokes Point		Stokes Lagoon		Herschel Island			Nuneluk
	1974	1975	1974	1975	1974	1975	1985	1974	1975	1974	1975	1974	1975	1985	1974
Freshwater/Anadromous															
Arctic cisco	10.7	7.0	7.9	16.7	37.6	5.3	52.9	53.3	27.1	64.7	34.6	72.3	45.3	74.8	52.1
Least cisco	82.8	90.5	83.7	76.7	32.7	60.7	22.5	27.1	64.6	20.5	59.2	3.3	45.3	2.7	2.3
Arctic charr	0.1	0.0	0.0	0.0	7.0	0.0	3.1	11.5	0.0	10.0	0.3	20.7	0.0	1.8	18.6
Broad whitefish	0.0	0.0	0.5	0.0	0.8	1.3	0.4	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Humpback (lake) whitefish	1.0	0.0	0.5	0.0	3.9	0.0	0.4	0.0	2.1	0.2	0.6	0.0	0.0	0.0	0.0
Round whitefish	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inconnu (sheefish)	1.5	1.0	0.0	0.0	2.9	2.0	0.5	0.0	4.2	0.0	0.9	0.0	0.0	0.0	0.1
Arctic grayling	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Burbot	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Boreal (rainbow) smelt	3.3	0.5	4.0	0.0	2.1	14.7	4.4	0.0	0.0	0.0	0.0	0.0	2.1	3.8	0.0
Northern pike	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
Marine															
Arctic cod	0.1	0.0	0.5	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Fourhorn sculpin	0.2	1.0	3.0	4.2	8.7	8.7	9.3	8.2	2.1	4.4	0.0	3.7	6.1	13.1	25.4
Saffron cod	0.0	0.0	0.0	0.0	0.2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Pacific herring	0.0	0.0	0.0	0.0	0.0	2.7	0.1	0.0	0.0	0.2	1.6	0.0	0.6	0.0	0.0
Capelin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
Arctic lamprey	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arctic flounder	0.0	0.0	0.0	0.0	3.6	0.7	5.8	0.0	0.0	0.0	0.9	0.0	0.0	2.9	1.4
Starry flounder	0.0	0.0	0.0	0.0	0.3	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7. Species and group composition (percent) of fish caught in gill nets and seines during 1985 and in fyke nets during 1986 in Phillips Bay, Yukon Territory.

Species/Group	Gillnet[1]	Seine[1]	Fyke Net[2] >250 mm	Fyke Net[2] <250 mm	Total
Arctic cisco	53.0	60.7	6.5	30.5	37.1
Least cisco	22.3	5.1	6.4	8.0	14.3
Arctic charr	3.1	0.2	-	-	1.2
Rainbow smelt	4.3	2.7	-	-	5.6
Broad whitefish	.4	0.0	-	-	0.6
Lake whitefish	.5	<0.1	-	-	0.3
Inconnu	.6	<0.1	-	-	<0.1
Total Anadromous	84.2	68.7			59.2
Arctic flounder	3.4	1.6	-	-	31.5
Fourhorn sculpin	21.2	29.5	-	-	7.4
Saffron cod	0.3	0.0	-	-	1.7
Arctic cod	0.0	0.0	-	-	0.1
Total marine	24.6	31.1			40.7
Total Freshwater	<0.1	<0.1			0.1
Total Number	8,195	4,835			142,797

[1] Bond and Erickson (1987)
[2] Bond (1987)

The above comparisons suggest that results of the Yukon studies differ from the Prudhoe Bay/Sagavanirktok Delta studies mainly because of sampling techniques (i.e., gill nets and seines vs. fyke nets) and sampling effort. However, there are differences between the one Yukon coast fyke net study and the Alaska studies. In Alaska, the dominant marine species was Arctic cod followed by fourhorn sculpin; together they accounted for between 48 and 83% of the catches in the Prudhoe Bay/Sagavanirktok region over six years of study (see Table 1). In the Yukon, Arctic flounder was by far the dominant marine species and Arctic cod were almost absent (Table 7). In addition, Arctic and least cisco appeared to be more abundant in the Phillips Bay region in 1986 than in Prudhoe Bay in 1984 (e.g. seasonal catch was 73,470 in 2 fyke nets vs. 24,350 in 11 nets, respectively).

A notable feature of the fish community along the Yukon coast is the virtual absence of broad whitefish (Tables 6 and 7). Nearly all of the few specimens taken have been adults (Kendel et al. 1975; Bond and Erickson 1987). The main exception to this was in the 1986 Phillips Bay fyke net study where about 67% of the 937 broad whitefish caught were young-of-the-year (W. Bond, pers. comm.). The low numbers of broad whitefish in all Yukon studies suggests that this coast is not an important summer feeding area or a major migratory pathway for this species. Although the Mackenzie River is a major source of broad whitefish (see Table 2), it appears that the conditions along the exposed Yukon coast typically do not facilitate westward dispersal from the delta.

Although total fish catch varies among location and year, the distribution patterns for Arctic cisco and least cisco along the Yukon coast appear to differ. Least cisco are more abundant near the Mackenzie Delta than to the west, and only a few occur as far west as Herschel Island (Kendel et al. 1975; Griffiths et al. 1975; Baker 1986; Bond and Erickson 1987). On the other hand, Arctic cisco are distributed along the Yukon coast and westward into Alaskan waters (Kendel et al. 1975; Griffiths et al. 1975, 1977; Baker 1986; Bond and Erickson 1987).

The occurrence of Arctic charr has varied considerably among location and year of study. Kendel et al. (1975) found charr to be moderately abundant in the Stokes Point and Herschel Island area in 1974, but virtually absent from both locations in 1975. Baker (1986) collected few Arctic charr near Herschel Island in 1985. Bond and Erickson (1987) reported that charr were not common in Phillips Bay (3.1% of the gill net catch during 1985 and 1.2% of the fyke net catch in 1986) despite that fact that the Babbage River which flows into Phillips Bay supports a spawning population (Bain 1974).

Fish Species of Concern

Broad Whitefish

The low numbers of both large and small broad whitefish collected suggest that this species does not make extensive use of the Yukon coast as either a migration route or summer feeding habitat. Consequently, it is unlikely that developments at King and Stokes points would have any impact on the species. Accordingly, broad whitefish will not be addressed further.

Arctic Charr

Arctic charr spawn and/or overwinter in most of the major river systems along the Canadian and Alaskan North Slope between the Mackenzie and Colville rivers (see Table 2). They have been reported as being uncommon in most studies along the Yukon coast. Bond and Erickson (1987) and Bond (1987) did not find charr to be abundant in the Phillips Bay area in either 1985 or 1986 despite the fact that the Babbage River contains a spawning population. The absence of charr in the area may reflect their euryhaline and eurythermal nature which allows them to disperse freely and rapidly along the entire Yukon/Alaskan Beaufort Sea coast, resulting in low densities and consequently low catches in most areas.

The intensive monitoring studies conducted around causeways in Alaska suggest that these structures do not have any significant effects on the distribution, movement and habitat utilization of Arctic charr. This finding, combined with the low abundance of charr along the Yukon coast, indicates that charr are not likely to be seriously affected by the King Point and Stokes Point causeways.

Least Cisco

Although direct documentation is lacking, it is thought that the majority of least cisco found along the Yukon coast during summer originate from spawning and/or overwintering grounds in the Mackenzie River system (see Table 2). Although catch-per-unit-effort of least cisco decreases westward along the Yukon coast, Stokes Point and King Point are important migratory routes and/or summer feeding habitat for this species. Consequently, least cisco is a species of primary concern.

Arctic Cisco

It is believed that Arctic cisco that utilize the coastal waters of the Yukon Beaufort Sea originate in the Mackenzie River drainage. They are the most abundant anadromous species collected along the coast. Present data suggest that the Yukon region is an important migratory route and/or summer feeding habitat for both large and small individuals. In addition, many young-of-the-year Arctic cisco migrate to Alaska along the Yukon coast and return as adults to the Mackenzie (Gallaway et al. 1983). Any impact to this distribution pattern could affect recruitment into Alaskan waters. Arctic cisco are a species of major concern.

Movement and Distribution Patterns of Key Fish Species

Because of the paucity of time series data along the Yukon coast, much of the following material is conjecture, based primarily on our

understanding of basic biology of northern fishes and more detailed studies that have been performed in Alaska. The latter studies have greatly increased our understanding of fish movement patterns and reactions in relation to changing conditions.

Least Cisco

The historical catch data indicates that least cisco abundance declines from east to west along the Yukon coast and reaches very low levels just west of the Canadian/Alaskan border (Mann 1974; Griffiths et al. 1975; Kendel et al. 1975; Bond and Erickson 1987). This range generally corresponds to the Mackenzie River Habitat Unit described by Gallaway et al. (1988) based upon nearshore temperature profiles (see Fig. 8). Although least cisco have been taken in the coastal waters of the extreme eastern Alaskan Beaufort Sea, numbers have been small (Roguski and Komaruk 1972; Griffiths et al. 1977; Griffiths 1983).

Movements in the open-water season are thought to consist of a dispersal away from the Mackenzie River early in the summer, followed by a return to spawning and/or overwintering grounds in or near the Mackenzie River prior to freeze-up. The timing and extent of the out-migration has not been studied but may be a function of ice conditions along the coast. In years characterized by a high percentage of easterly winds, nearshore ice cover dissipates rapidly and probably provides fish with a greater opportunity for westward dispersal. Conversely, west winds can delay breakup, and the extensive ice cover could delay westward dispersal and possibly limit the extent of the coastal migration. The degree to which dispersal may be affected by ice cover is unknown at present.

Bond (1987) found that large (>250 mm) least cisco were already present in the Phillips Bay region by 23 June when fyke net sampling began. Peak catch levels occurred in early July, and fish remained abundant until early August after which time numbers declined and were low for the remainder of the season. This abundance pattern for large least cisco was similar to that reported for the 1985 Phillips Bay gill

net study (Bond and Erickson 1987). In 1986 small least cisco (<250 mm) first moved into the Phillips Bay region in late July, abundances peaked in early August and then declined toward the end of the study period in mid-September (Bond 1987). These small individuals consisted primarily of age 1^+ and age 2^+ fish; young-of-the-year fish were seldom captured. In 1985, age 0^+ least cisco were caught sporadically. In 1986 numbers were also small and catches sporadic (Bond and Erickson 1987).

The return migration of least cisco to the Mackenzie River occurs sometime during August. Mann (1974) reported that seasonal high CPUE at Stokes Point Lagoon was in early August, and that catch dropped to low levels by the end of the month. He speculated that this decline was a result of fish returning to the Mackenzie River. A similar late-season trend was observed by Bond and Erickson (1987) and Bond (1987). In a study conducted in the Mackenzie Delta, strong upstream migrations of large least cisco were observed between 12-26 August, 1974 (Percy 1975). All of these results are consistent with the September and early October spawning migrations that have been documented in the upper reaches of the Mackenzie River (Hatfield et al. 1972; Stein et al. 1973).

The presence of age 0^+ to age 2^+ least cisco in Phillips Bay during 1985 appears to contradict the concept of their preference for warmer, less saline conditions. The highest catches of these individuals often occurred during periods of increasing salinities and decreasing temperatures. The Alaskan experience has shown that synoptic surveys do not detect driving environmental mechanisms because they fail to take into account the dynamics of the system. Cold, marine situations may in fact be the most optimal conditions available to the fish if adjacent waters are even colder and more saline (Neill and Gallaway 1988). In addition, fish may choose to pass through inhospitable conditions to reach their destination and thus may be caught in cold saline water.

Kendel et al. (1975) found that anadromous fish, including least cisco, were typically more abundant in nearshore, warmer, less saline water as opposed to the colder, more marine, offshore waters. Similar results were reported for Phillips Bay (Bond and Erickson 1987). Thus, it appears that

least cisco along the Yukon coast show a similar preference for warm low salinity water as do least cisco in Alaskan waters.

Arctic Cisco

Arctic cisco found in both the Alaskan and Canadian Beaufort Sea are believed to originate from spawning stocks in the Mackenzie River system (Gallaway et al. 1983). In the Beaufort Sea, but excluding areas east of the Mackenzie River, overwintering areas have been documented only in the Mackenzie, Colville and Sagavanirktok rivers. Despite the limited number of overwintering sites, large Arctic cisco are found along the entire Canadian/Alaskan Beaufort Sea coast in summer (Roguski and Komaruk 1972; Craig and Mann 1974; Griffiths et al. 1975, 1977; Kendel et al. 1975; Percy 1975; Griffiths 1983; Schmidt et al. 1988; Lawrence et al. 1984; West and Wiswar 1984). This suggests that Arctic cisco make extensive seasonal movements, during the open-water period, back and forth from a few widely separated overwintering areas. The extent to which individuals who overwinter in Alaskan rivers disperse into Yukon waters to feed and vice versa in unknown.

The use of fyke nets in Phillips Bay revealed that large numbers of young-of-the-year (20 to 80 mm FL) Arctic cisco were present from late July until sampling was terminated in mid-September (Bond 1987). An unknown portion of these fish might be recruited to Alaska and eventually take up residence in the Colville and Sagavanirktok deltas. In 1985, Fawcett et al. (1986) found that small age 0^+ Arctic cisco first appeared in catches near the Colville River on 26-27 August, approximately 35 days after they had first appeared in Phillips Bay (Bond and Erickson 1987). However, it is evident that many small Arctic cisco do not migrate to Alaska but remain in Canadian waters. Small Arctic cisco were still abundant in seine hauls and fyke nets in Phillips Bay during 1985 and 1986 when sampling was terminated in late August and mid-September, respectively. In addition, small Arctic cisco were abundant in the Mackenzie Delta and along the Tuktoyaktuk Peninsula throughout the summer from 1978 to 1980 (Lawrence et al. 1984).

Along the Yukon coast, most large Arctic cisco were captured at nearshore shallow water stations as opposed to deeper (5 m depth) offshore

stations (23.3 vs. 0.39 fish/h, respectively; Bond and Erickson 1987). Typically, temperatures were higher and salinities lower in the shallower waters than offshore. Present information suggests that Yukon Arctic cisco show the same preference for warmer brackish water as do those in the Prudhoe Bay/Sagavanirktok region.

Effects of Structures on Yukon Fish

The primary difference between causeways that have been constructed in Alaska and any proposed for the Yukon coast is size. The two major Alaskan causeways are much longer than any that have been discussed for the Yukon (3.9 and 3.1 km vs. 0.7 and 1.0 km, respectively). In addition, depths are greater along the Yukon coast and the unprotected nature of the coast results in very active shorelines (i.e., more movement of beach gravel due to wave action) compared to the Alaska situation. The width of the nearshore band of warm less saline water may also be quite different. It is important to keep these differences in mind when considering the possible effects on fish of structures along the Yukon coast.

Stokes Point Causeway

The hypothetical development at Stokes Point shown in Figure 15A consists of a solid-fill structure extending approximately 700 m offshore to 5 m depth. In addition, a dredged channel extends from the end of the causeway out to the 10 m depth contour.

Easterly Winds

Easterly winds will cause a disruption in the westerly flow of brackish coastal water by producing an upward mixing of colder saline offshore water which will replace the brackish water on the downwind (west side) of the causeway. The areal extent and intensity of this upwelling cannot be predicted accurately, given the present state of knowledge about the Yukon coast. It should be noted that the intense marine upwelling area west of West Dock extends only for about 2 km west of the structure. The build-up of brackish coastal water on the east side of the Stokes Point causeway will probably result in the development of a buoyant plume that will be deflected around the tip of the causeway. This plume is likely to become diffuse and intersect the shore several kilometres to the west.

Under easterly winds, Arctic and least cisco of all size-classes moving to the west would likely bypass the pocket of upwelled marine water by moving around the causeway in conjunction with the brackish water plume. Similar winds would probably not affect large fish of either species on the return migration because of their greater tolerance of colder, saline conditions, their ability to move rapidly through areas of less than optimal conditions and the strong homing drive present in fish which are approaching spawning. Tagging studies in Alaska have consistently shown that causeways and causeway-induced changes in the oceanographic regime do not block the movements of large Arctic and least cisco returning to overwintering areas.

The greatest concern is for small Arctic and least cisco migrating back to the Mackenzie River to overwinter. If east winds persisted, movement back to the east would require small fish to migrate through the cold, marine water on the west side of the Stokes Point causeway. What effect this would have on these small fish is unknown at present.

Westerly Winds

As was the case in the Alaskan situation, westerly or southwesterly winds probably will not produce pronounced changes in waters around the causeway (see Effects of Causeways on Physical Oceanography section). There is a possibility that exceptionally strong flows around the causeway tip could induce upwelling on the eastern side of the structure. The intensity and extent of this event would still not be as great as that produced on the west side during easterly winds.

Present knowledge suggests that, under westerly winds, there would be no significant causeway-induced effects on large Arctic and least cisco. However, the situation for small Arctic and least cisco is not clear. During periods of west winds, small westward-moving fish have to swim against currents. If they also encountered cold, saline water their movements may be slowed or blocked until a major wind reversal. As explained in more detail in 'Effects of Structures on Population Levels' the effect of this could be significant if Arctic cisco movements into Alaska were greatly reduced or stopped.

King Point Causeway

The King Point structure would combine a 1000 m solid-fill causeway with a breakwater of equal length located to the east of the causeway (Fig. 15B).

Easterly Winds

The response of the water masses in the vicinity of the King Point structure, under the influence of easterly winds, would be similar to those described above for the Stokes Point causeway; namely, the development of a pool of colder, saline water on the west side of the structure, due to an upward mixing at the end of the causeway. The extent and intensity of the upwelling may be greater at the King Point causeway, since it extends further into the sea and to a greater depth. Upwelling may also occur on the east side of the causeway due to a

similar upwelling situation caused by the seaward end of the breakwater. The westward movement of surface waters would cause the development of a buoyant plume of brackish water that would be deflected westward around the King Point structure in the same way as described for the Stokes Point causeway. Due to the depths involved at King Point, it is possible that a two-layered system could develop on the east side of the causeway; that is, a surface layer of brackish water overlaying the colder, saline offshore water.

As was the case of the Stokes Point causeway, east winds would probably not affect the distribution patterns of large Arctic and least cisco around the King Point structure. These large individuals could move around the structure in the buoyant plume and continue on their way west. Large fish returning during easterly winds could encounter the pool of colder, saline water on the west side of the causeway but, for the same reasons explained in the previous section it is likely that they could move around the structure with little difficulty.

It is thought that small Arctic and least cisco would have little trouble moving west around the King Point causeway and breakwater with the westward flowing buoyant plume of brackish water. However, the westerly currents and the cold water could delay the return migration of small individuals, as described above for the Stokes Point causeway. The effects on Arctic cisco populations would not be as great since a portion of those that move west do not return until they become sexually mature. At present, there are insufficient data to determine the effects on small Arctic and least cisco that must return to the Mackenzie Delta to overwinter.

Westerly Winds

Persistent westerly winds result in a net movement of water to the east. This could cause the warmer brackish water in Phillips Bay to flow east along the coast toward King Point. At the same time, strong westerly winds typically bring ice into the Mackenzie Bay area and close to shore at King Point. This could result in the formation of a band of

cold, relatively brackish water next to the coast in the King Point area. The westward movement of water past the tip of the King Point causeway could also produce an upwelling of cold, saline water between the causeway and the breakwater, as was the case for the West Dock causeway in Alaska during westerly winds.

The effects of the King Point causeway and breakwater on fish during west winds would be similar to those described for the Stokes Point causeway. Typically, the distribution patterns of large Arctic and least cisco would probably not be significantly affected. The case for small Arctic and least cisco is again not as clear due to their lower tolerance of low temperatures and higher salinities, and their slower swimming speeds. Effects would presumably be least on fish moving east in fall and greatest on those moving west in the early part of the open-water season.

Summary

The changes in physical oceanography due to the presence of causeways along the Yukon coast, would be similar to those observed in Alaskan. The major changes (i.e., pooling of cold, saline water on the west side of the structures) would occur under easterly winds. Similar conditions would occur on the east side of the causeways under westerly winds but would probably not be as intense. Data from the Alaskan studies suggests that the effects of the causeways on large (>250 mm FL) Arctic and least cisco and on all sizes of Arctic charr are minimal. It is probable that the same would be true for the effects of structures along the Yukon coast given their smaller size and the wider tolerances of the larger fish to lower temperatures and higher salinities. However, the situation for small Arctic and least cisco (< 250 mm FL) is not clear at this time, particul rly for the very small individuals (<100 mm FL) that make up a large portion of the fish along the coast (Bond 1987).

Effects of Structures on Population Levels Of Key Species

The ultimate question is whether any of the potential causeway-induced impacts could affect the population levels of important fish species. Alaskan studies have provided strong evidence that causeways do, under certain conditions, block the longshore movement of certain species of anadromous fish, at times excluding them from considerable portions of their summer feeding grounds. What has not been established is whether these direct effects have had a substantial impact on the overall population. For example, small least cisco from the Colville River are probably the most susceptible to having their longshore dispersal disrupted by the West Dock causeway. Yet Moulton and Fechhelm (1988) estimated that only about 5% of the Colville River population migrates to the Prudhoe Bay area during any one season. In addition, prevailing wind patterns during three of the six study years have prevented small least cisco from dispersing into the causeway area altogether. Thus, although the direct impact to longshore dispersal has been documented, it is possible that only a small and insignificant fraction of the overall population is affected.

Least Cisco

Although least cisco that utilize the Yukon coastal waters during the open-water season probably originate in the Mackenzie River, it is not known what proportion of the Mackenzie River population this represents, or if they are derived from one or more stocks. This makes it difficult to determine least cisco population level effects of causeways along the Yukon coast. The potential for population effects would be greatest if Yukon coast least cisco were from a single Mackenzie stock and if the stock maintained a fidelity to the summer feeding area. Under these conditions a blockage of the western movement of small least cisco out of the summer feeding area to overwintering sites in the Mackenzie Delta could result in a reduction in the numbers of the affected stock. On the other hand, if the least cisco that utilize the Yukon coast are from a mixture of stocks then population effects would be less likely.

Arctic Cisco

The problem of assessing population level effects of Arctic cisco is similar to that described for least cisco. Arctic cisco are found not only along Yukon and Alaskan coasts, but also in the Mackenzie Delta (Percy 1975) and the along Tuktoyaktuk Peninsula (Jones and DenBeste 1977; Bond 1982; Hopky and Ratynski 1983; Lawrence et al. 1984). The lack of fyke net data from the latter areas prevents even preliminary assessments of the relative importance of the Mackenzie Delta, the Tuktoyaktuk Peninsula, the Yukon coast and the Alaskan Coast as summer feeding grounds.

However, unlike least cisco, a portion of the Canadian Arctic cisco apparently use the Yukon coast to migrate to Alaskan waters. There are two important questions that must be considered in order to determine what the impacts on Arctic cisco stocks are: (1) what percentage of the Mackenzie Arctic cisco migrate to Alaska? and (2) do the Arctic cisco that migrate to Alaska consistently come from a single or a mixture of stocks within the Mackenzie system? If the percentage that migrates to Alaska is small, then any impact to those migrants could have little effect on the overall population, even if none of the migrates returned to spawn. On the other hand, if the migrants represent a large portion of the Mackenzie stock, any disruption of the migration along the Yukon or Alaskan coasts could have substantial impacts on the population. If the migrant Arctic cisco are from a single Mackenzie system stock then the population level impacts on the affected stock would be similar to those just described.

Even if the percentage is high, a single causeway probably will not significantly affect Arctic cisco population levels; however, a series of causeways, with each one adding to the impact of the others, could product a synergistic effect that may lead to a decrease in Arctic cisco numbers, either through direct mortality of the age 0^+ migrating fish or by a reduction in fecundity due to reduction in condition factor caused by loss of feeding habitat. The long term result of these impacts

could be a reduction in both the commercial catch in the Colville River and in all the subsistant harvests between the Colville and Mackenzie deltas.

Causeway Breaches

Causeway breaches should be considered as a mitigation to impacts of structures along the Yukon coast on anadromous fish. In the Yukon situation one of the primary concerns is the along shore movement of small Arctic and least cisco. Several studies in this region show that anadromous fish used the nearshore waters, often within the first 20 m of shore, when moving or migrating along the coast (Bond 1987; Bond and Erickson 1987). Given these factors, it would appear that the best location for breaches in Yukon causeways would be within 20 m of shore, since this placement would permit small fish to move relatively unimpeded along the coast, and reduce the potential impact of the causeway.

Siltation is a potential problem with a breach placed this close to shore along a high energy beach, this is particularly true for the King Point site. This has been a major problem with the narrow breach (15 m wide) in the West Dock causeway which regularly silts in, dramatically reducing its effectiveness. Although this breach is dredged-out several time each year it remains essentially closed to fish migration for most of the open-water season. In order to avoid this situation for a Yukon causeway, the breach would have to be much wider and/or configured in some fashion as to minimize the siltation process.

SUMMARY

The hypothetical Stokes Point structure consists of a solid-fill causeway and a dredged channel, while that at King Point consists of a solid-fill causeway and breakwater.

The oceanographic conditions at Stokes Point and King Point are variable particularly under east winds when the Mackenzie River plume can either occur right next to shore or be displaced offshore, due to upwelling. The potential effects of the structures at Stokes Point and King Point on the physical processes would be similar. Under east winds, both could result in the formation of a pool of cold, saline water on the west side and a buoyant plume of warmer brackish water flowing around the tip of the structures. These conditions would persist until a major wind reversal. Under west or southwest winds, the effects would likely be smaller since physical characteristics would be more uniform around the structures.

In gill net and seine studies conducted along the Yukon coast, three anadromous species: Arctic and least cisco and Arctic charr have accounted for an average of 87% (range: 66 to 98%) of the total catch. Only two of these, Arctic cisco and least cisco, occur in abundance in the region of concern with small (<250 mm FL) individuals being the most abundant group during the open-water season.

Arctic and least cisco both originate from Mackenzie River stocks. They have somewhat similar dispersal patterns along the Yukon coast. Large individuals (>250 mm FL) of both species have already moved out along the coast by late June. Most least cisco disperse only as far east as Herschel Island, while Arctic cisco have a much more extensive dispersal range. Both species return to overwintering and/or spawning areas in the Mackenzie system by mid-September. Some small Arctic and least cisco have dispersed along the coast by late June or early July, the main pulses of these species start appearing in late July. Both species remain abundant along the coast into September, before returning to overwintering areas in the Mackenzie system. In addition, a portion of the small age 0^+ Arctic cisco migrate over to Alaskan waters, where they take up residence and do not return until they are ready to spawn.

The King Point or the Stokes Point structures would probably not affect large Arctic and least cisco, due to the relatively small size of the Yukon developments compared to those in Alaska, and the swimming

abilities of these fish. The case for small Arctic and least cisco is not as clear, since insufficient information is available on the distribution patterns and movements to allow a determination of the impacts of the proposed structures on these size groups.

Population level effects for least cisco and Arctic cisco would depend on the percentages of the Mackenzie population of each species that utilizes the Yukon coast, and if the these fish are from a single or a mix of stocks. The answers to these questions are not known at the present time.

PART 3: ADEQUACY OF AVAILABLE INFORMATION AND IMPORTANT DATA GAPS IN RELATION TO YUKON CAUSEWAYS

INTRODUCTION

A major problem in evaluating the effects of the Prudhoe Bay/Sagavanirktok Delta causeways on anadromous fish has been the paucity of biological and physical data collected prior to construction of the causeways. This has made comparisons of fish movement and habitat use before and after causeway construction virtually impossible. It is difficult to overemphasize the magnitude and seriousness of this problem. While multimillion dollar fisheries studies have been conducted over a period of several years after causeway construction, extremely little effort was expended in Alaska prior to causeway construction. In most cases, data that exist were obtained for reasons other than later comparisons to post-causeway conditions. For example, the only fisheries studies conducted in the Prudhoe Bay region prior to West Dock construction were some short-term gillnet sampling efforts to determine species composition. Even in cases where daily fyke net and oceanographic data were collected prior to construction (e.g. the 1982 study in the Sagavanirktok Delta as reported by Griffiths et al. 1983), comparisons with post-construction conditions are not always a simple matter. In this case, the one-year baseline data were collected in a year characterized by variable winds with a high frequency of westerlies, low wind speeds, and above normal temperatures. These conditions have not reoccurred in any of the post-construction years to date. It is evident that in order to account for natural variability within the system, fish, oceanographic and meteorological data need to be collected over a number of years.

Oceanographic data

A major gap in the oceanographic data along the Yukon coast is the lack of detailed data on seasonal and annual variability of temperature and salinity regimes in the vicinity of possible causeways. To date,

the only full-season oceanographic data sets available in the nearshore waters of the region are those associated with the 1985 and 1986 fish studies in Phillips Bay (Bond and Erickson 1987; W. Bond, pers. comm.). In order to determine the effects of causeways on nearshore waters a program is needed to identify water masses and assess their horizontal and vertical scales, and their responses to wind. Ideally such data should be collected daily over an area centered on the proposed causeway sites, extending up to 3 km offshore and approximately 5 km on each side of the structure. Stations should separated by no more than 0.3 to 0.5 km perpendicular to shore and 1 to 2 km in the along-shore direction. In addition, daily meteorological data (wind direction and speed) should be collected in conjunction with the oceanographic data, since the winds are the main driving force of the system. A complementary, or possibly alternative, approach would be to use the very high resolution (30 m) thematic mapper data from the Landsat satellite to resolve the coastal zone oceanographic features. Ancillary data such as on-site wind observations, moored current measurements and large-scale NOAA satellite imagery would also be useful to the study.

Fish Data

At present fisheries data are extremely limited along the Yukon coast, and consist primarily of : (1) the two years of surveys conducted by Kendel et al. (1975), (2) a seasonal gill net and seine study in Phillips Bay carried out by Bond and Erickson (1987) and (3) a seasonal fyke net study conducted in Phillips Bay during the summer of 1986 (W. Bond, pers. comm.).

The following sections deal with the strengths and shortcomings of the historical data base for the Yukon coast. Included are some assessments of techniques and approaches used in the 1981-1986 Prudhoe Bay studies which may be useful for assessing the impact of the proposed causeways along the Yukon coast.

Baseline Data

A major problem that has continuously confronted the Prudhoe Bay environmental monitoring programs has been a lack of pre-causeway biological and physical baseline data. It has been been found that without pre-causeway baseline data it is virtually impossible to determine if post-causeway migratory patterns and distributions of fish are distinctly different from those that existed prior to causeway construction. While efforts and associated costs of environmental monitoring in Prudhoe Bay/Sagavanirktok Delta area have increased steadily over the past six years, investigators have still not been able to overcome the lack of apriori data.

The situation along the Yukon coast today is similar to that in the Prudhoe Bay area prior to the construction of the first causeway. Although the studies of Kendel et al. (1975), Bond and Erickson (1987), and Bond (1987) have provided information on species composition along the coast and timing of movements and distribution of fish in the Phillips Bay region, there are still many aspects of Yukon coast fisheries that remain unanswered (see above). In the event that causeway construction becomes probable, the level of effort aimed at establishing a detailed, a priori data base should be increased. In order to be able to address the relevant questions adequately, with respect to impacts of causeways, it is also important to have a data base on fish, oceanography and meteorology collected over a number of years to take into account the natural variability within the system.

Limitations of the Available Data

A limiting factor in determining the distribution and migratory patterns of anadromous fish along the Yukon coast is the brief survey nature of the majority of the data. Relative to the intensive studies conducted in Alaska gillnetting and seining efforts along the Yukon coast have been conducted on an intermittent basis (Griffiths et al. 1975; Kendel et al. 1975; Baker 1986; Bond and Erickson 1987). A second limiting factor is fishing gear. Seines typically sample only a small

area at a fixed point in time and typically capture small, slow-moving fish. While gill nets have been used to sample over periods of up to 24 h at a time, they have been employed only on a weekly or biweekly basis. Gill nets tend to catch larger fish. By comparison, fyke nets used in the Prudhoe Bay region typically operate round-the-clock throughout the open-water season and catches are much more representative of the fish commonly present in the area. These limitations have been documented along the Yukon coast as a result of the 1986 Phillips Bay fyke net study (Bond 1987; Table 7).

Lack of time-series data along the Yukon coast is a major limitation in assessing the migratory patterns and habitat utilization of anadromous fish. Prudhoe Bay studies have shown that fish often move along the coast in pulses that may last for only a few days. Even within a given 24-h period, fish probably encounter fyke nets as schools rather than being caught on a continuous basis. Identifying such brief pulses in fish movement are essential in evaluating natural movement patterns, habitat use and subsequently causeway impacts. The lower frequency of sampling effort and spatial scope of gillnet and seining efforts greatly increases the probability of missing these important longshore dispersal and migratory patterns.

The relative abundances of different size classes of fish along the Yukon coastal waters have also been obscured by gear type. This can be seen in the results of the 1985 Phillips Bay study (Bond and Erickson 1987). Of the 749 least cisco taken in variable-mesh gill nets over the entire season, all were greater than 150 mm FL. Conversely, over 90% of 217 least cisco taken by seine were less than 150 mm, with nearly 85% of the total catch measuring between 25 to 74 mm in length. Had the authors not employed seines, there would have been no indication that small (<150 mm) least cisco were in the area. However, since the efforts expended by each gear type are not directly comparable, the relative abundance of large fish versus small fish of a given species cannot be determined. The 1986 Phillips Bay fyke net study clearly demonstrated this, by showing that not only were small Arctic and least cisco much more abundant in the region than gillnet and seine studies

had suggested, but they were much more abundant, in terms of numbers, than larger individuals (Table 7).

Important Data Gaps

Numerous aspects of the biology of anadromous fish have been investigated in Prudhoe Bay/Sagavanirktok Delta region in order to identify impacts of oil development. Some of the approaches used have provided informative and at times critical data in assessing impacts. In addition, several important data gaps have been identified that have direct application to the Yukon coast situation. The following outlines the major data gaps and suggests possible studies that might be conducted in order to fill them.

Population Studies

It has been shown that the assessment of the significance of potential impacts on Arctic cisco of hypothetical causeways along the Yukon coast and real causeways in Alaska is limited by the lack of knowledge needed to determine (1) what portion of the Mackenzie River Arctic cisco migrate to Alaskan waters? and (2) is the group that does migrate over to Alaska a single stock or a mixture of several stocks? Studies required to address this data gap include mark/recapture studies conducted simultaneously in the Alaskan and Canadian Beaufort Sea, catch comparison studies conducted simultaneously on both sides of the Mackenzie Delta (e.g. Phillips Bay and Point Atkinson) and genetic stock separation studies. The mark/recapture studies would provide information on the number of large Arctic cisco that migrate over to Alaskan waters during the open-water season or vice versa. Conducting simultaneous fyke net studies on both sides of the Mackenzie Delta would provide some information on the relative abundance of Arctic cisco on both sides of the delta. In addition, it would provide an indication of the percentage of the Mackenzie stock of Arctic cisco that utilizes the Yukon coast. Genetic stock separation studies would provide information on whether the Arctic cisco that use the Yukon coast and migrate to Alaska come from a single stock or a mixture of stocks.

Mark/recapture

Mark/recapture studies in the Prudhoe Bay/Sagavanirktok Delta region have been a valuable asset in determining causeway effects. Some of the more important contributions have been 1) to identify a major causeway-induced blockage to longshore movement of least cisco (Moulton et al. 1986; Fechhelm et al. 1988); 2) to enable the tracking of individual groups of fish through the environment (Critchlow 1983; Griffiths et al. 1983; Moulton et al. 1986; Cannon et al. 1987a; Fechhelm et al. 1988); 3) to provide evidence that large Arctic cisco emigrate from Alaskan waters to the Mackenzie Drainage (Moulton et al. 1986; Fechhelm et al. 1988; W. Bond, pers. comm.); and 4) to provide evidence that causeways do not prevent large least and Arctic cisco from returning to overwintering and/or spawning grounds (Cannon and Hachmeister 1987).

In terms of environmental impact, mark/recapture efforts are one of the most valuable aposteriori investigative tools. They provide evidence of some causeway-induced impacts after the structures have been built. The primary disadvantage of the technique is that substantial numbers of fish must be marked. In the six years of study in Prudhoe Bay/Sagavanirktok Delta area over 350,000 fish have been Floy-tagged, dye-marked, freeze-branded and fin-clipped, and while results have not always been definitive, the general understanding of fish movements and timing within the region has been greatly enhanced.

Age/Length Data

The determination of the age/length structure of anadromous fish populations is extremely useful in biological studies and has applications to environmental impact assessment. In the case of coastal causeways, any abnormalities or shifts in the length-at-age structure for a particular population could be a strong indictor of effect. Such abnormalities can be determined by comparison with population norms for

large regions such as the Mackenzie River zone, or perhaps even the entire Canadian/Alaskan Beaufort Sea.

At present, the appropriate age/length data have been collected in Phillips Bay area (Bond and Erickson 1987; W. Bond, pers. comm.), so that a data base of conditions prior to any development already exists.

Condition Factors

Length/weight data from winter studies conducted in the Sagavanirktok and Colville deltas provided some evidence that Arctic cisco may not attain sufficient energy reserves during the preceding summer season to carry them over the winter (Schmidt et al. 1988). By comparing length/weight data from different habitats and from different locations across the Beaufort Sea coast it may be possible to determine if the condition of fish in areas of development is significantly different from those in nondeveloped areas.

Feeding/Prey Studies

Probably the least cost-effective studies conducted in the Prudhoe Bay area has been the fish feeding and prey distribution surveys (Moulton et al. 1986; Knutzen et al. 1986; Cannon et al. 1987b). The original intent was to sample the distribution of fish prey on a short-term and continuous basis and compare results to fish stomach analyses to determine if (1) specific species of fish relied exclusively on specific prey items, (2) if causeway-induced shifts in prey distribution caused concomitant shifts in fish distribution. While the results have been interesting from a scientific perspective, they have been somewhat disappointing as a tool for assessing impacts, particularly given the expenditures of time, effort and money that have been involved.

The primary problem with the approach centres around the dynamics of the system. Although fish used in these analyses are taken from nets adjacent to where the epibenthic samples are collected, it is not possible to determine, with any confidence, if the fish feed in the

vicinity of the net or if they feed elsewhere and then move into the area where they are caught. Thus a comparison of stomach contents against prey levels in the region of capture can lead to erroneous speculation that fish are selecting for or against a certain prey species when in fact they may merely be opportunistic feeders.

The fish feeding/prey distribution surveys have been scientifically intriguing, and have provided interesting, and detailed information of the feeding habits of anadromous fish. However, the main goal of the surveys has not been met, and given the expenditures of time and money that have supported these studies, it would be advisable to carefully consider this option prior to initiating similar surveys along the Yukon coast.

SUMMARY

The physical oceanographic data available at present are insufficient for a determination of how the proposed structures would alter the water masses at either King Point or Stokes Point. To address this data gap would require oceanographic and meteorological data collected on a daily basis over the open-water season, on a grid pattern 3 km by 5 km centered on the proposed causeway. An additional or possible alternative program would be to use the very high resolution (30 m) thematic mapper from the Landsat satellite to resolve the coastal zone oceanographic features.

The major problem in the Alaska monitoring programs is the lack of pre-construction fisheries data for comparison. At present there are no seasonal fisheries data available for the hypothetical development sites, although, there are seasonal gillnet and seine data from 1985, only and daily fyke net data from 1986 at Phillips Bay, located between King Point and Stokes Point.

Baseline fisheries data should be collected over a number of years at proposed development sites to account for the natural variability within the system.

In the case of Arctic cisco, the two most important unanswered questions are (1) what percentage of the Mackenzie Drainage Arctic cisco migrate over to Alaska? and (2) are these fish from a single stock or are they composed of a mixture of stocks? Studies to address this data gap include mark/recapture studies, fyke net catch comparison studies conducted simultaneously on both sides of the Mackenzie Delta and genetic stock separation studies.

In Alaska, mark/recapture studies have provided the most detailed information on distribution patterns and timing of movements. In addition, these programs led to the realization that Arctic cisco that overwinter in the Colville and Sagavanirktok deltas are migrants from Canada.

The collection of age/length and length/weight data, especially for small fish (<250 mm FL), over a number of years, at both development and control sites can be compared to determine if there are any causeway-induced habitat changes.

LITERATURE CITED

Adams, A.B. and T.C. Cannon. 1987. Overwintering study. 1985 Final Rep. Vol. 7, for Endicott Envir. Monitoring Prog. for U.S. Corps of Engineers, Anchorage AK. 33 p.

Alexander, V. and R.T. Cooney. 1979. Ice edge ecosystem study: primary productivity, nutrient cycling and organic matter transfer. Final Rep. Inst. Mar. Sci., Univ. of Alaska, Fairbanks, AK. 165 p.

Allan, R. B. and G. R. Mackenzie-Grieve. 1983. Water quality and biological survey of coastal waters near Stokes Point, Yukon-Beaufort Sea coast. Envir. Can., Envir. Protection Serv. Reg. Prog. Rep. No. 83-23. 70 p.

Allan, R. B. and G. R. Mackenzie-Grieve. 1984. Water quality and biological survey of coastal waters near Stokes Point, Yukon-Beaufort Sea coast. Envir. Can., Envir. Protection Serv. Reg. Prog. Rep. No. 84-06. 39 p.

Alt, K.T. and D.R. Kogl. 1973. Notes on the whitefish of the Colville River, Alaska. J. Fish. Res. Board Can. 30:554-556.

Bain, L.H. 1974. Life histories and systematics of arctic char (Salvelinus alpinus L.) in the Babbage River system, Yukon Territory. M. Sc. Thesis, Univ. Calgary, Alberta. 156 p. Also: Arctic Gas Biol. Rep. Ser. 18(1). 156 p.

Baker, R.F. 1986. Fisheries survey of Herschel Island, Yukon Territory from 9 July to 12 August 1985. Unpubl. Rep. by North/South Consult. Inc., Winnipeg, Man. for Dept. Renew. Res. Yukon Territory, Whitehorse YT. 44 p.

Beamish, F.W.H. 1970. Oxygen consumption of largemouth bass, Micropterus salmoides, in relation to swimming speed and temperature. Can. J. Zool. 48: 1221-1228.

Bendock, T. N. 1979. Beaufort Sea estuarine fishery study. Environ. Assess. Alaskan Cont. Shelf. Final Rep., Vol. 4. Biological Studies. BLM/NOAA OCSEAP. p. 670-729.

Bendock, T. and J. Burr. 1985. Freshwater fish distributions in the central arctic coastal plain (Topagoruk River to Ikpikpuk River). Alaska Dep. Fish and Game, Fairbanks, AK. 30 p.

Bickham, J., S. Carr, B. Hanks, D. Burton and B. Gallaway. 1988. Genetic analysis of population variation in the arctic cisco using electrophoretic, flow cytometric, and mitochondrial DNA restriction analyses. Biol. Papers Univ. Alaska, Fairbanks. (in press)

Biosonics, Inc. 1984. Prudhoe Bay Waterflood Project Fish Monitoring Program. 1983. Prepared for Dep. Army, Alaska District, Corps of Engineers, Anchorage. 161 p.

Birch, J.R., D.D. Lemon, D.B. Fissel and H. Melling. 1987. Arctic data compilation and appraisal - Vol. 12. Beaufort Sea: Physical Oceanography-currents, water levels and waves. 1914-1986. (Revised and up dated of Vol. 7). Can. Data Rep. Hydro. Ocean Sci. Vol. 12. 459 p.

Bond, W. 1987. Highlights of fisheries investigations conducted in Beaufort Coastal waters at Phillips Bay, Yukon Territory, Canada. Presentation to 14th Ann. Meet. Alaska Chapt., Amer. Fish. Soc. Fairbanks, AK. 16-19 November 1987.

Bond, W. 1982. A study of the fishery resources of Tuktoyaktuk Harbour, southern Beaufort Sea coast, with special reference to life histories of anadromous coregonids. Can. Tech. Rep. Fish. and Aquat. Sci. No. 1119. 90 p.

Bond, W. and R. Erickson. 1982. Preliminary results of a fisheries study of two freshwater lake systems on the Tuktoyaktuk Peninsula, Northwest Territories. Can. Data Rep. Fish. Aquat. Sci. No. 348. 62 p.

Bond, W. and R. Erickson. 1985. Life history studies of anadromous coregonid fishes in two freshwater lake systems on the Tuktoyaktuk Peninsula, Northwest Territories. Can. Tech. Rep. Fish. Aquat. Sci. No. 1336. 61 p.

Bond, W. A. and R. Erickson. 1987. Fishery data from Phillips Bay, Yukon, 1985. Can. Data Rep. Fish. Aquat. Sci. No. 635. 39 p.

Borstad, G.A. 1985. Water colour and temperature in the southern Beaufort Sea: remote sensing in support of ecological studies of the bowhead whale. Can. Tech. Rep. Fish. Aquat. Sci. 1350. 68 p. + Plates.

Bradstreet, M. S. W. and D. B. Fissel. 1986. Zooplankton of a bowhead whale feeding area off the Yukon coast in August 1985. Unpubl. Rep. by LGL Ltd., King City, Ont. and Arctic Sciences Ltd., Sidney. B. C. for Indian and Northern Affairs Canada. 155 p.

Bradstreet, M. S. W., D. H. Thomson and D. B. Fissel. 1987. Zooplankton and bowhead whale feeding in the Candian Beaufort Sea, 1986. Unpubl. Rep. by LGL Ltd., King City, Ont. and Arctic Sciences Ltd., Dartmouth, Nova Scotia for Indian and Northern Affairs Canada (in press).

Brett, J.R. 1971. Energetic responses of salmon to temperature. A study of some thermal relations in the physiology and freshwater ecology of sockeye salmon (Oncorhynchus nerka). Amer. Zool. 11: 99-113.

Brett, J.R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. J. Fish. Res. Board. Can. 21: 1183-1226.

Burns, B.M. 1973. The climate of the Mackenzie Valley - Beaufort Sea Volume I. Envir. Can., Atmosph. Envir. Climat. Stud. No. 24, U.D.C. 551.582 (712).

Cannon, T.C. and L.E. Hachmeister. 1987. Integration and assessment. 1985 Final Rep. Vol. 1, for Endicott Envir. Monitoring Prog. for U.S. Army Corps of Engineers, Anchorage, AK. 128 p.

Cannon, T.C., B. Adams, D. Glass and N. Troy. 1987a. Fish distribution and abundance. 1985 Final Rep. Vol. 6, for Endicott Envir. Monitoring Prog. for U.S. Army Corps Of Engineers, Anchorage, AK. 129 p + Appendices.

Cannon, T.C., M.S. Brancato and S.C. Jewett. 1987b. Fish prey survey. 1985 Final Rep. Vol. 7, for Endicott Envir. Monitoring Prog. for U.S. Army Corps of Engineers, Anchorage, AK. 74 p + Appendices.

Corkum, D.M. and P. McCart. 1981. A review of the fisheries of the Mackenzie Delta and nearshore Beaufort Sea. Can. MS. Rep. Fish. and Aquat. Sci. No. 1613. 55 p.

Coutant, C.C.. 1977. Compilation of temperature preference data. J. Fish. Res. Board Can. 34: 739-745.

Craig, P.C. 1977a. Ecological studies of anadromous and resident populations of Arctic char in the Canning River drainage and adjacent coastal waters of the Beaufort Sea, Alaska. Arctic Gas Biol. Rep. Ser. 41(1). 116 p.

Craig, P.C. 1988. Adaptations of anadromous fishes in the arctic environment. Biol. Papers Univ. Alaska, Fairbanks, AK (in press).

Craig, P.C. and L. Haldorson. 1981. Beaufort Sea barrier island-lagoon ecological process studies: final report, Simpson Lagoon. Part 4. Fish. In: Environ. Assess. Alaskan Cont. Shelf. Final Rep. Prin. Invest., BLM/NOAA, OCSEAP, Boulder, Colorado. 7:384-678.

Craig, P.C. and G.J. Mann. 1974. Life history and distribution of arctic cisco (Coregonus autumnalis) along the Beaufort Sea coastline in Alaska and the Yukon Territory. Arctic Gas Biol. Rep. Ser. 20(4). 27 p.

Craig, P.C. and P. McCart. 1974. Fall spawning and overwintering areas of fish populations along routes of proposed pipeline between Prudhoe Bay, Alaska, and the Mackenzie Delta 1972-73. Arctic Gas Biol. Rep. Ser. 15(3). 36 p.

Craig, P.C., W.B. Griffiths, L. Haldorson and H. McElderry. 1982. Ecological studies of Arctic cod (Boreogadus saida) in Beaufort Sea coastal waters, Alaska. Can. J. Fish. Aquat. Sci. 39:395-406.

Craig, P.C., W.B. Griffiths, S. Johnson and D. Schell. 1984. Trophic dynamics in an arctic lagoon. P. 347-380. In: P. Barnes, D. Schell, and E. Reimnitz (eds.), Alaskan Beaufort Sea Ecosystems and Environment. Academic Press, New York, New York.

Critchlow, K. 1983. Fish report, Prudhoe Bay Waterflood Project environmental monitoring program, 1982. Rep. by Woodward-Clyde Consultants for Dept. Army, Alaska District, Corps of Engineers, Anchorage, AK. Vol. 3, Chap. 5. 327 p.

Davidge, D.A. and G.R. Mackenzie-Greive. 1986. A follow up water quality and biological survey of King Point and Stokes Point, Yukon - Beaufort Sea Coast. Envir. Can. Envir. Protect. Serv. Draft Rep.

Dew, C.B. 1983. Anadromous and marine fish. 59 p. In: Oliktok Point and vicinity: 1982 environmental studies, final report. Rep. by Woodward-Clyde Consultants for Atlantic Richfield Co. (ARCO) Alaska, Anchorage, Alaska.

Fawcett, M., L. Moulton and T. Carpenter. 1986. Colville River fishes: 1985 biological report. Chap. 2. Rep. by Entrix Inc. for Atlantic Richfield Co. (ARCO) and North Slope Borough, Barrow, AK. 138 p.

Fechhelm, R. 1988. Movement and distribution patterns of arctic anadromous fishes in a modified coastal habitat. Biol. Papers Univ. Alaska, Fairbanks. (in press).

Fechhelm, R. G. and D. B. Fissel. 1988. Wind-driven recruitment of Canadian Arctic cisco into Alaskan waters. Can. J. Fish. Aquat. Sci. (in press).

Fechhelm, R.G., J.S. Baker, W.B. Griffiths and D.R. Schmidt. 1988. Localized movement patterns of least cisco (Coregonus sardinella) and arctic cisco (C. autumnalis) in the vicinity of a solid-fill causeway. Biol. Papers Univ. Alaska, Fairbanks. (in press).

Feder, H. and S,G. McGee. 1982. Prudhoe Bay waterflood project epifaunal monitoring program. Rep. by Inst. Mar. Sci. Univ. Alaska, Fairbanks, AK, for U.S. Army Corps of Engineers, Anchorage, Ak. 149 p. + Appendices.

Feder, H.M. and D. Schamel. 1976. Shallow water benthic fauna of Prudhoe Bay.p. 329-359. In: Hood and Burrell (eds.). Assessment of the Arctic Marine Environment: selected topics, Univ. Alaska, Inst. Mar. Sci.

Ferguson, R.G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Board Can. 15: 607-624.

Fissel, D. B., M. S. W. Bradstreet and J. Moen. 1987a. Water mass distributions in the Canadian Beaufort Sea. In: Oceans 87 Conference Proceedings, Marine Technology Society and IEEE Ocean Engineering Society, Washington, D. C. (in press).

Fissel, D. B., J. R. Marko, J. R. Birch, G. A. Borstad, D. N. Truax and R. Kerr. 1987b. Water mass distributions. p. 11-133. In: W. J. Richardson (ed.), Importance of the Eastern Alaskan Beaufort Sea to feeding bowhead whales, 1985-86. NTIS PB87- Rept. from LGL Ecol. Res. Assoc. Inc., Bryan, TX, for U. S. Minerals Manage. Serv., Reston, VA. 547 p.

Fry, F.E.J. and J.S. Hart. 1949. Swimming speed of goldfish at different temperatures. J. Fish. Res. Board Can. 7: 169-175.

Furniss, R.A. 1975. Inventory and cataloging of arctic area waters. Alaska Dept. Fish and Game, Annu. Rep. 16:1-47.

Gallaway, B., W. Griffiths, P. Craig, W. Gazey and J. Helmericks. 1983. An assessment of the Colville River delta stock of Arctic cisco (Coregonus autumnalis) migrants from Canada? Biol. Pap. Univ. Alaska. 21:4-23.

Gallaway, B.J., W.J. Gazey and L. Moulton. 1988. Population trends for Arctic cisco (Coregonus autumnalis) in the Colville River of Alaska as reflected by the commercial fishery. Biol. Pap. Univ. Alaska, Fairbanks, Ak (in press).

Gilbertson, L., L. Hachmeister, C. Prewitt and D. Glass. 1987. Integration and assessment. Draft Rep. for 1986 Endicott Envir. Monitoring Prog. for U.S. Army Corps of Engineers, Anchorage, AK. 276 p + Appendices.

Glass, D., C. Whitmus, and M. Prewitt. 1986. Fish distribution and abundance. In: Endicott Environmental Monitoring Survey, 1986. Rep. to Army Corps of Engineers, Anchorage, Ak. 188 p.

Grainger, E. H. and J. E. Lovrity. 1975. Physical and chemical oceanographic data from the Beaufort Sea, 1960 to 1975. Can. Dept. Fish. Mar. Serv. Tech. Rep. 590.

Griffiths, W.B. 1983. Fish. P. 176-222. In: Environmental characterization and biological use of lagoons in the eastern Beaufort Sea. Rep. by LGL Inc., Ecol. Res. Assoc. Bryan, TX. for MMS, BLM/NOAA, OCSEAP.

Griffiths, W. B. and R. A. Buchanan. 1982. Characteristics of bowhead feeding areas. p. 65-145 In: W. J. Richardson (ed.), Behavior, disturbance responses and feeding of bowhead whales, Balaena mysticetus in the Beaufort Sea, 1980-81. NTIS PB86-152170. Rept. from LGL Inc., Ecol. Res. Assoc. Bryan, TX, for U.S. Bureau of Land Manage., Washington, DC. 456 p.

Griffiths, W.B. and R. Dillinger. 1981. Beaufort Sea barrier island-lagoon ecological process studies: final report, Simpson Lagoon. Part 5. Invertebrates. In: Environ. Assess. Alaskan Cont. Shelf. BLM/NOAA, OCSEAP, Final Rep. 8:1-198.

Griffiths, W.B. and B. Gallaway. 1982. Prudhoe Bay Waterflood Project, fish monitoring program. Rep. by LGL Alaska Res. Assoc. for Woodward-Clyde Consultants, Anchorage, Alaska and the U.S. Army Corps of Engineers, Anchorage, Alaska. Vol. 4. 143 p.

Griffiths, W.B, P.C. Craig, G.L. Walder and G.J. Mann. 1975. Fisheries investigations in a coastal region of the Beaufort Sea (Nunaluk Lagoon, Y.T.). Arctic Gas Biol. Rep. Ser. 34(2). 219 p.

Griffiths, W.B., J. DenBeste and P. Craig. 1977. Fisheries investigations in a coastal region of the Beaufort Sea (Kaktovik

Lagoon, Barter Island, Alaska). Arctic Gas Biol. Rep. Ser. 40. 190 p.

Griffiths, W.B., R. Fechhelm, D. Schmidt, B. Gallaway, R. Dillinger, W. Neill, W. Gazey and J. Baker. 1983. Fish ecology. P. 1-323. In: B. Gallaway and R. Britch (eds.), Environmental summer studies (1982) for the Endicott Development, fish ecology, Vol. 3. Rep. by LGL Alaska Res. Assoc. and North. Tech. Serv. for Sohio Alaska Petroleum Co., Anchorage, Alaska.

Hablett, T.R. 1979. Fish investigations conducted within the National Petroleum Reserve on the North Slope of Alaska, 1977-78. P. 337-406. In: Vol. 2. Studies of selected wildlife and fish and their use of habitats on and adjacent to the National Petroleum Reserve in Alaska 1977-1978 (105 c). Field Study 3, U.S. Dep. Interior, Anchorage, Alaska.

Hachmeister, L.E., K.S. Short, G.C. Schrader, K.B. Winnick and J.W. Johannessen. 1987. Oceanographic Monitoring. 1985 Final Rept. Vol. 3, for Endicott Envir. Monitoring Prog. for U.S. Army Corps of Engineers, Anchorage, AK. 162 p + Appendices.

Harper, J.R. and S. Penland. 1982. Beaufort Sea sediment dynamics. Rep. by Woodward-Clyde Consultants, Victoria, B.C. for Geol. Surv. Canada, Dartmouth, Nova Scotia.

Hatfield, C.T., J.N. Stein, M.R. Falk, C.S. Jessop and D.N. Shepherd. 1972. Fish resources of the Mackenzie River Valley. Environ. Can., Fish. Serv., Winnipeg, Manitoba. Inter. Rep. Vol. 1, 247 p., Vol. 2, 289 p.

Holmquist, C. 1965. The amphipod genus Pseudalibrotus. J. Zool. Syst. Evol. 3 (5): 19-46.

Hopky, G. A., D. B. Chiperzak and M. J. Lawrence. 1986. Seasonal temperature, salinity and density data for the Canadian Beaufort Sea Shelf: 1984-85. Can. Data Rep. Fish. Aquat. Sci.

Hopky, G. and R. Ratynski. 1983. The relative abundance, spatial and temporal distribution, age and growth of fishes in Tuktoyaktuk Harbour, N.W.T., 28 June to 5 September 1981. Can. MS. Rep. Fish. Aquat. Sci. No. 1713. 71 p.

Jobling, M. 1981. Temperature tolerance and the final preferendum-rapid methods for the assessment of optimal growth temperatures. J. Fish. Biol. 19: 439-455.

Jones, M.L. and J. Den Beste. 1977. Tuft Point and adjacent coastal area fisheries project. Rep. by Aquat. Environ. Ltd. for Imperial Oil Ltd., Calgary. 152 p.

Kendel, R.E., R.A. Johnston, U. Lobsiger and M. Kozak. 1975. Fishes of the Yukon coast. Beaufort Sea Tech. Rep. 6. 114 p.

Kentzen, J.A., M.S. Brancato and S.C. Jewett. 1986. Fish prey surveys (drop nets). Unpubl. Rep. by Envirosphere Company for U.S. Army Corp Engineers, Anchorage AK. 122 p. + Appendicies.

Kogl, D.R. and D. Schell. 1974. Colville River Delta fisheries research. P. 483-504. In: Environ. Studies of an Arctic Estuarine System - Final Rep. U.S. Environ. Protect. Agency, Ecol. Res. Ser. EPA-660/3-75-026.

Lawrence, M., G. Lacho and S. Davies. 1984. A survey of the coastal fishes of the southeastern Beaufort Sea. Can. Tech. Rep. Fish. Aquat. Sci. No. 1220. 178 p.

Mann, G.J. 1974. Life history types of the least cisco (Coregonus sardinella, Vallenciennes) in the Yukon Territory, North Slope and eastern Mackenzie River delta drainages. Arctic Gas Biol. Rep. Ser. 18(3). 160 p. (Also: Master's thesis. Univ. Alberta, Edmonton, Canada).

McCart, P.J., W.B. Griffiths, C. Gossen, L.H. Bain and D. Tripp. 1974. Catalogue of lakes and streams in Canada along routes of the proposed Arctic Gas pipeline from the Alaskan/Canadian border to the 60th parallel. Arctic Gas Biol. Rep. Ser. 16. 262 p.

McDonald, B.C. and C.P. Lewis. 1973. Geomorphic and sedimentological processes of rivers and coast, Yukon Coastal Plain. Envir. Soc. Comm. North. Pipl. Rep. No. 73-39. Inform. Can. Cat. No. R72-12173. 245 p. + Maps.

McPhail, J.D. and C.C. Lindsey. 1970. The freshwater fishes of northwestern Canada and Alaska. Bull. Fish. Res. Board Can. 173. 381 p.

Moulton, L. and M. Fawcett. 1984. Oliktok Point fish studies - 1983. Rep. by Woodward-Clyde Consultants for Kuparuk River Unit, ARCO Alaska, Inc., Anchorage, AK.

Moulton, L., M. Fawcett and T. Carpenter. 1985. Lisburne development environmental studies: 1984, fish. Rep. by Entrix Inc. for ARCO-Alaska Inc., Anchorage, AK.

Moulton, L., B. Gallaway, M. Fawcett, W. Griffiths, K. Critchlow, R. Fechhelm, D. Schmidt and J. Baker. 1986. 1984 Central Beaufort Sea fish study. Waterflood Monitoring Program Fish Study. Rep. prepared for Envirosphere Co., Anchorage, AK. 300 p.

Moulton, L.L. and T.R. Jennings. 1987. Assessment of the Colville River fall fishery in 1986. In: Colville River Fish Study. 1986 Annual Rep. for ARCO Alaska, Inc., North Slope Borough, and the City of Nuiqsuit, Anchorage, AK. 49 p.

Moulton, L.L. and R.G. Fechhelm. 1988. Summary of species characteristics and distribution in the study area. Comprehensive Marine Report, Chap. 9. Prudhoe Bay Waterflood Monitoring Program. Dep. Army Alaska District, Corps Engineers. Anchorage, AK.

Neill, W. and B.J. Gallaway. 1988. "Noise" in the distributional responses of fish to environment: an excercise in deterministic modelling motivated by the Beaufort Sea experience. Biol. Pap. Univ. of Alaska, Fairbanks, AK.

Nelson, T., T.C. Cannon, W.R. Olmsted and K.C. Wiley. 1987. Surveys of domestic and commercial fisheries in the central and eastern Beaufort Sea. 1985 Final Rep. Vol. 7, for Endicott Envir. Monitoring Prog. for U.S. Army Corps of Engineers, Anchorage, Ak. 36 p.

Oesthus, O.D. 1976. Breeding of migratory Arctic char (Salvelinus alpinus) in brackish and salt water. Presented at: Council Meeting 1976. International Council for the Exploration of the Sea.

Percy, R.J. 1975. Fishes of the outer Mackenzie Delta. Can. Dept. Environ., Victoria, B.C., Beaufort Sea Tech. Rep. 8. 114 p.

Peterson, R.H., A.M. Sutterlin and J.L. Metcalfe. 1979. Temperature preference of several species of Salmo and Salvelinus and some of their hybrids. J. Fish. Res. Board Can. 36:1137-1140.

Roguski, E.A. and E. Komaruk. 1972. Monitoring and evaluation of arctic waters with emphasis on the North Slope drainages. Alaska Dep. Fish and Game, Annu. Rep. 12:1-22.

Savoie, M.A. and J. Colonell. 1988. Ocean processes data review. Draft Comprehensive Marine Report. by Envirosphere Company, Bellevue, WA. for ARCO Alaska, Inc., Anchorage, AK. 72 p.

Savoie, M.A. and D.E. Wilson. 1983. Physical processes monitoring program for 1982. Chapter 3 In: Prudhoe Bay Waterflood Envir. Monitoring Prog., 1982. By Envirosphere Company for U.S. Army Corps of Engineers, Anchorage, AK.

Savoie, M.A. and D.E. Wilson. 1984. Preliminary draft, 1984 Physical processes monitoring program. In: Prudhoe Bay Waterflood Envir. Monitoring Prog., 1984, for U.S. Army Corps of Engineering, Anchorage, AK.

Savoie, M.A. and D.E. Wilson. 1986. Physical processes monitoring program for 1984. Chapter 2 In: Prudhoe Bay Waterflood Envir. Monitoring Prog., 1984. By Envirosphere Company for U.S. Army Corps of Engineers, Anchorage, AK

Schell, D.M., P. Ziemann, D. Parrish and E. Brown. 1982. Foodweb and nutrient dynamics in nearshore Alaskan Beaufort Sea waters. Cumulative Summary Rep. for NOAA, OCSEAP.

Schmidt, D., W. Griffiths and L. Martin. 1988. Fish overwintering sites in the Sagavanirktok and Colville rivers. Biol. Pap. Univ. Alaska, Fairbanks. (in press)

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Bull. Fish. Res. Board Can. 184. 966 p.

Sekerak, A., W. Griffiths and N. Stallard. 1985. Aquatic investigations in response to dredging in the Meade River, Alaska. Rep. by LGL Environ. Res. Assoc. for the North Slope Borough, Barrow, AK. 172 p.

Short, K.S., G.C. Schrader, L.E. Hachmeister and C.J. Van Zee. 1987. Oceanography 1986. Draft Report Prepared by Envirosphere Company, Bellevue, WA. for U.S. Army Corps of Engineers, Anchorage, Ak. 276 p + Appendices.

Smith, M. and R. Glesne. 1982. Aquatic studies on the North Slope of the Arctic National Wildlife Refuge, 1981 and 1982. U.S. Fish Wildl. Serv., Fairbanks, AK., Fish. Resour. Prog. Rep. FY83-1. 71 p.

Stein, J.N., C.S. Jessop, T.R. Porter and K.T.J. Chang-Kue. 1973. An evaluation of the fish resources of the Mackenzie River valley as related to pipeline development. Vol. I. Environ.-Soc. Comm., North. Pipelines, Task Force North. Oil Dev., Rep. 73-1. Ottawa. 121 p.

Thomson, D. H., D, B. Fissel, J. R. Marko, R, A. Davis and G. A. Borstad. 1986. Distribution of bowhead whales (Balaena mysticetus) in relation to hydrometeorological events in the southeastern Beaufort Sea, 1980-1983. Envir. Stud. Revol. Fund Rep. No. 028. Ottawa. 119 p.

Truett, J. 1981. Beaufort Sea barrier island-lagoon ecological process studies: Final Rept., Simpson Lagoon. Part 7. Synthesis, Impact Analysis, and Monitoring Approach. Res. Unit 467: In: Envir. Asses. Alaskan Cont. Shelf, Final Rept. Prin. Invest. Vol.7. BLM/NOAA, OCSEAP. Boulder, CO.

Ward, D. and P. Craig. 1974. Catalogue of streams, lakes and coastal areas in Alaska along routes of the proposed gas pipeline from Prudhoe Bay to the Alaskan/Canadian border. Arctic Gas Biol. Rep. Ser. 19. 381 p.

West, R. and D. Wiswar. 1984. Fisheries investigation of the of the Arctic National Wildlife Refuge, Alaska, 1984. U.S. Fish and Wildl. Serv., Fairbanks, Fish. Resour. Prog. Rep. No. FY85-1. 47p.

Whitmus, C.J., T.C. Cannon and S.S. Parker. 1987. Age, growth, and condition of anadromous fish. 1985 Final Rep,, for Endicott Monitoring Prog. Vol. 7, for U.S. Army Corps of Engineers, Anchorage, Ak. 34 p.

Woodward-Clyde Consultants. 1983. Lisburne development area: 1983 environmental studies--final report. Rep. by WWC for ARCO-Alaska Inc., Anchorage, AK., 722 p.